# NAVAL POSTGRADUATE SCHOOL
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# THESIS

**SPREADSHEET DECISION SUPPORT MODEL FOR MK 16 UNDERWATER BREATHING APPARATUS REPAIR PARTS INVENTORY MANAGEMENT**

by

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December, 1994

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## ABSTRACT

This thesis proposes a spreadsheet-based decision support model for determining the most effective repair parts inventory for the MK 16 Underwater Breathing Apparatus (MK 16). Incorporating U.S. Navy demand information, the model provides the inventory manager the ability to modify repair parts inventories as changes occur to the order and shipping times, tempo of operations, or the number of MK 16 assigned. The thesis explores the current methods of MK 16 repair parts inventory design and recommends changes that permit the inventory manager to model an improved inventory within the constraints of each specific scenario. While providing inventory managers the ability to experiment with "what if" scenarios, the spreadsheet also provides the commanding officer greater control over unit readiness.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| APL | Allowance Parts List |
| BRF | Best Replacement Factor |
| CASREP | Casualty Report |
| COSAL | Coordinated Shipboard/Shorebased Allowance List |
| DDP | Demand Development Period |
| DoD | Department of Defense |
| EOD Det | Explosive Ordnance Disposal Detachment |
| EOD MU | Explosive Ordnance Disposal Mobile Unit |
| FLSIP | Fleet Logistics Support Improvement Program |
| FMSO | Navy Fleet Material Support Office |
| FSW | Depth in Feet of Sea Water |
| MCC | Material Control Code |
| MEC | Military Essentiality Code |
| MK 16 | MK 16 Mod 0 Underwater Breathing Apparatus. |
| MCM | Mine Countermeasures |
| MODFLSIP | Modified Fleet Logistics Support Improvement Program |
| MRU | Minimum Replacement Unit |
| MS/OR | Management Sciences/Operations Research |
| OPTEMPO | Operations Tempo |
| OSK | Operations Support Kit |
| PMR | Planned Maintenance Requirement |
| POP | Population |
| RSS | Ready Service Spare |
| SCUBA | Self Contained Underwater Breathing Apparatus |
| SPECWAR | Naval Special Warfare Units |

| | |
|---|---|
| SPCC | Ships Parts Control Center |
| 3M | Maintenance and Material Management Program |
| TOR | Technical Override |
| TRF | Technical Replacement Factor |
| O-Level | Organization Level Maintenance |
| O&ST | Order and Shipping Time |

# I. INTRODUCTION

Repair parts are critical to maintaining the battlefield readiness of most warfighting systems. As these systems become more sophisticated and complex, the added cost of this refinement leads to fewer actual systems in the field while increasing their impact on mission success. The MK 16 Underwater Breathing Apparatus (MK 16) is one system that has grown dramatically in capability, complexity and cost. Designed for Mine Counter Measures (MCM) operations, this electronically controlled diving equipment is a significant improvement over previous options. The MK 16's ten-fold increase in effectiveness over its predecessor was accompanied by a 10-fold increase in the number of repair parts. Ships Parts Control Center (SPCC) lists 341 different types of replaceable parts for the MK 16. Out of those, 257 are replaceable at the user level (O-Level) with 184 classified as essential to the MK 16 mission. An additional 84 repair parts are listed as Depot level replaceable. The goal of this research is to identify the most effective method of determining the type and quantity of repair parts that best supports mission success during a deployment of the MK 16.

Each system that can be repaired by the organization that operates it maintains a supply of repair parts. Incorrect selection of the type of parts held in inventory, or too few of them, leads to shortages that make the system unavailable for battle. Too many, or unnecessary repair parts, is a mis-allocation of the command's budget; items more valuable to the mission are not funded because of the hidden cost of excess repair parts inventory. The costs of holding inventory include capital investment, storage, and losses from obsolescence and deterioration. Government Accounting Office surveys of DoD activities identified recent holding costs ranging from 11% to 23% of the total cost of the inventory annually. (Linville, 1994)

With fewer, more complex systems assigned to accomplish each mission, the ability to keep all systems battlefield-ready becomes directly linked to the management of the inventory of repair parts held at the O-Level repair facility. Blanchard describes the problem as viewed from the civilian sector:

> Too much inventory may ideally respond to the demand for spares. However, this may be costly, with a great deal of capital tied up in inventory. In addition, much waste could occur, particularly if system changes are implemented and certain components become obsolete. On the other hand, providing too little support results in the probability of causing the system to be inoperative due to stockout, which can also be costly. In general, it is desirable to obtain an economic balance...(Blanchard, 1992, p. 60)

The cost of a stockout during military operations is measured in terms of failed or delayed missions. The process of balancing the cost of inventory against the cost of mission failure is, at best, complex and is least understood by those who suffer when stockout occurs.

An equation that determines the appropriate number of repair parts requires several pieces of information.

- An estimate of the time between ordering a repair part and actually receiving it is recorded as order and shipping time (O&ST).
- The probability that the part will fail or be demanded by the O-Level user during O&ST.
- The number of similar parts that the repair part is supporting.
- The desired service level that the command intends for the system that the repair part supports: the probability that the part will be there when needed. (Blanchard, 1992, p. 57)

In equation form, this probability is:

$$P = \sum_{n=0}^{S} \frac{R(-\ln R)^n}{n!}, \qquad where \;\; R = e^{-K\lambda t} \qquad (1.1)$$

and where

$P$ = probability of having a particular repair part when required. This is also called the protection level.

$S$ = number of spare parts carried.

$R$ = reliability of the repair part, failures per unit time ($t$).

$K$ = quantity of parts used in a system.

With the exception of $K$, the population of similar parts, the correct values to use for this equation are not always easy to identify. Particularly, determining the desired service level, $P$, under the fiscal constraints of a budget requires the command to weigh mission success against available funds. In theory, achieving 100% probability that the part will be there when needed is never achievable over the long run at any cost. However, deciding that a 95% probability of the repair part being in-stock is acceptable, may mean you are accepting a 5% chance of a delayed or failed mission. As the inventory manager attempts to improve the in-stock probability, the associated costs increase exponentially with a per unit increase in protection level.

SPCC generates an Allowance Parts List (APL) for most repairable equipment used in the Navy. The Coordinated Shipboard/Shorebased Allowance List (COSAL) is a compilation of all the APLs for an operational afloat command. The APL identifies all parts that the O-Level repair facility may use during authorized repairs. Additional parts are listed for repairs conducted at depot level. The type and quantity of parts authorized to be held in-stock at the O-Level are based upon historical demand/usage, the mission criticality of the part, the military criticality of the system, and the population of the potential failed part at the facility.

When several systems using the same APL are maintained by the same O-Level maintenance facility, economies result from those systems using the same pool of inventory parts. SPCC relies on this advantage and lists the quantity of repair

parts authorized dependent upon the number of similar systems maintained by the command. An example from the MK 16 APL for a Harness Retainer Pin is provided as Figure 1.1. The number of MK 16 maintained by the command identifies which column applies. If twenty MK 16 were being supported, the command would use the APL (9-20) column and maintain a stock of 19 pins.

| | ON BOARD ALLOWANCE TABLE | | | | | | |
|---|---|---|---|---|---|---|---|
| | NUMBER OF EQUIPMENT/COMPONENTS | | | | | | |
| ITEM NAME | 1 | 2 | 3 | 4 | 5-8 | 9-20 | 21-50 |
| RETAINER; HARNESS PIN | 0 | 4 | 5 | 6 | 10 | 19 | 42 |

**Figure 1.1 Example of APL Column Listings.**

The assumption of a common maintenance facility and a shared inventory is critical to taking advantage of this economy. The policy becomes inadequate when operations require those systems (using a similar APL) to geographically separate and then operate from individual maintenance facilities. It is unlikely that we would separate systems from a unit like a ship and then expect that system to operate self-supported. However, it is common for small teams or detachments to share a common maintenance facility while in port, but to deploy independently. When the small teams or detachments do deploy, the APL/COSAL economies of scale collapse and each new maintenance facility is forced to operate with only a portion of the parent command's allowance; far short of what would have been allowed for whatever number of systems they have. Using the example in Figure 1.1, if a parent command with twenty systems were to establish five teams of four systems each, each team would be issued 20% of the parent command's APL allowance of 19, approximately four.

If each team had been assigned its own APL, the allowance would have been six each.

Assigning each team its own APL based on the number of systems assigned is certainly an option. Each team would maintain the SPCC allowance that permits self-sustaining operations whether at the parent command or deployed.

A survey of Explosive Ordnance Disposal Mobile Units (EOD MU) indicated several techniques for repair parts inventory modeling. Each EOD MU acts as a parent command to several EOD Detachments (EOD Det) using the MK 16. The process of instituting SPCC COSAL/APL support at these units is not complete at this date, contributing to the variety of techniques. Here are three examples.

One technique, used by a command without APL support, is to model an allowance based upon their own demand experience. Each EOD Det with four MK 16 is issued their own command-modeled allowance and the model developed from the initial parts allowance recommended by the manufacturer for four MK 16 when the systems were originally procured. This allowance was then augmented as indicated by the command's demand experience. This command also deploys a complete MK 16 spare in a lay-up status for emergency use.

A second technique, used by a command with APL support, is to issue a separate APL (4) column allowance for each EOD Det of four MK 16s. No spares are deployed and no additional parts are held by the parent command.

A third method, also a command with APL support, is for the parent command to maintain a full APL allowance for the total aggregate number of systems assigned. In addition, each EOD Det maintains a separate APL (4) allowance for their four systems. This command also augments their EOD Dets by deploying two MK 16 spares in lay-up status.

Inventory managers at parent commands struggle with the correct allocation of parts with a goal of attaining a service

level that ensures mission success without going over budget. They often simply estimate the proportion of repair parts to distribute to deploying EOD Dets that would best support the deployers without causing a stockout for the parent command or leave the next deployer unsupported. This estimate, based upon experience and expectations, is often at odds with the expectations of the deploying EOD Dets. Whether because of actual or perceived failure of the APL modeled inventory, inventory managers almost universally exceed the SPCC allowance for repair parts.

This thesis explores the application of a spreadsheet decision support model that assists inventory managers in selecting the best type and quantity of repair parts. Using demand data from SPCC and the formula described in equation (1.1), the inventory manager will have the flexibility to configure the repair parts allowance to meet the highest possible protection level within the constraints prescribed by the scenario. This flexibility has the potential to improve inventory design with both greater protection and lower costs. Although adaptable to several inventory problems, this spreadsheet will be modeled around the MK 16 scenarios described above.

Chapter II will describe the MK 16 equipment and the supply linkage a MK 16 EOD Detachment uses for provisioning and resupply as compared to the techniques SPCC uses for APL calculations. Chapter III will provide the logic behind spreadsheet analysis and the functions within the decision support model. Chapter IV will compare the cost to protection level relationships of the proposed spreadsheet model with current inventory practices. Chapter V will summarize the results and provide conclusions and recommendations for improvements to the current methods of MK 16 repair parts inventory management.

# II. BACKGROUND

## A. MK 16 EQUIPMENT AND OPERATIONS

### 1. Before the MK 16

As the sophistication of ocean mines increases with modern electronics, so does the complexity of countering that threat. Modern ocean mines employ a combination of electronic sensors to identify their targets and to trigger their explosive charge at the critical moment. Many ocean mines are sensitive to acoustic, magnetic and seismic signals.

As recently as 1986, Navy divers conducted MCM operations using Self-Contained Underwater Breathing Apparatus (SCUBA) tanks and regulators similar to those seen in the early "Sea Hunt" TV shows. The only modification to the two-hose regulator and tanks was to construct them of nonmagnetic materials. The MK VI, a semi-closed circuit underwater breathing apparatus, was also in use and provided borderline magnetic and acoustic safety for the diver. However, logistic support was stopped for the MK VI in 1979 and only marginal mission capability was maintained. (Walsh, 1989, p. 11)

Open-circuit SCUBA is limited to short duration dives because each breath the diver takes is exhausted into the water. The maximum depth is limited by the only authorized breathing medium, compressed air ($N_2O_2$), to 190 feet of seawater (FSW). Deeper than 190 FSW the nitrogen component ($N_2$) becomes increasingly toxic through the narcotic effects of nitrogen narcosis.

### 2. MK 16 Equipment

Today, Navy MCM diving operations rely heavily on the MK 16. (See Figures 2.1 and 2.2) The MK 16 meets military specifications for nonmagnetic and acoustically safe equipment and was designed primarily for MCM operations. The MK 16 is a closed circuit rebreather that recirculates the diver's

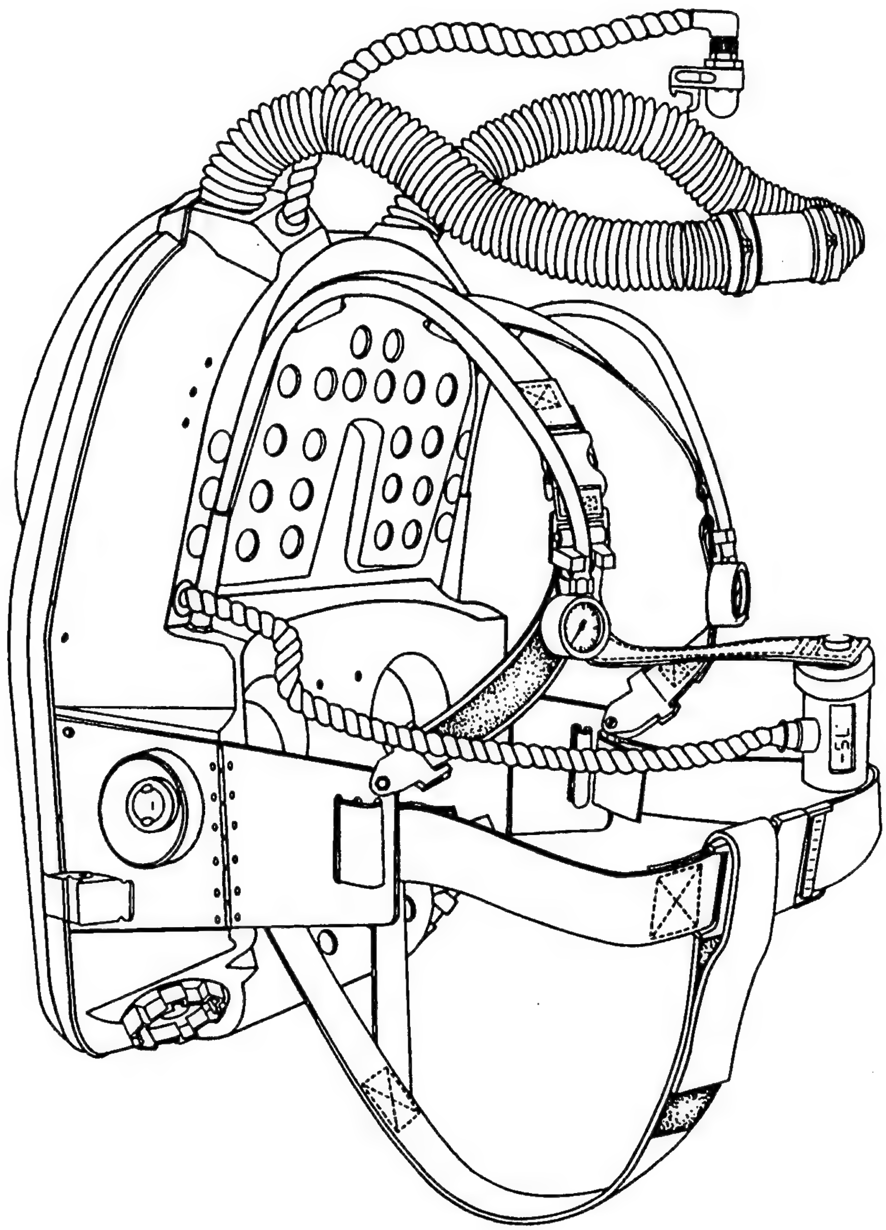

Figure 2.1 MK16 MOD 0 Underwater Breathing Apparatus (Courtesy of MK16 Program Office).

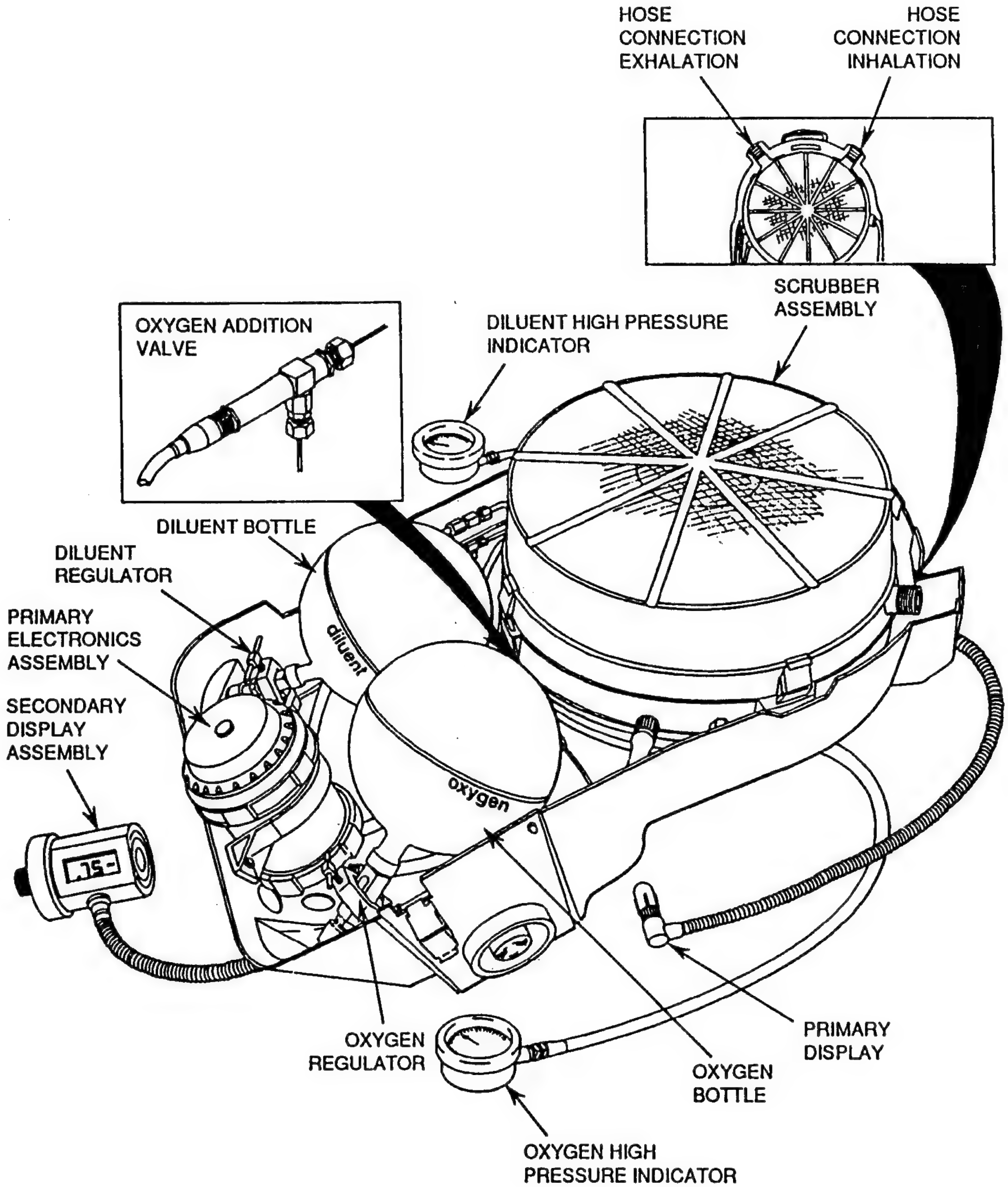


Figure 2.2 MK16 MOD 0 With Upper Housing Removed.

exhaled breath after removing the carbon dioxide ($CO_2$). The composition of the breathing medium is closely monitored by battery-powered electronics. The electronics package maintains the optimum mix of breathing gases by automatically adding small amounts of oxygen ($O_2$) or diluent gas from high pressure bottles. The mix can also be overridden by the diver during emergencies by using manual controls. (O&M Manual, 1990, p. 1-3) Pure oxygen is not used because of an increasing possibility of central nervous system oxygen toxicity when used deeper than 33 FSW. (Dive Manual, Vol. 2, p. 9-3) The diluent gas removes the toxic characteristics of $O_2$. Filtered air ($N_2O_2$) is used as diluent to a maximum depth of 150 FSW and a helium/oxygen mix ($HeO_2$) is used to a maximum depth of 300 FSW. The Navy currently limits the MK 16 to a maximum depth of 200 FSW because of the depth limitation of other support equipment required by the diver. Full 300 FSW certification is expected in 1995.

The closed circuit feature of the MK 16 greatly extends the time a diver can spend underwater. With the breathing gas recirculated and not expelled, diving duration is primarily limited by the ability of the absorbent canister to remove the $CO_2$ from the breathing medium. Depending upon the diluent gas used and the water temperature, the MK 16 is capable of supporting a diver for up to 300 minutes to a depth of 300 FSW.

### 3. MK 16 Procurements

The same closed-circuit, low acoustic and nonmagnetic features that make MK 16 effective with MCM operations also lend themselves to application by the Naval Special Warfare (SPECWAR) teams. EOD units have used the MK 16 operationally since 1986; SPECWAR units since 1993. Scheduled procurement of MK 16 over the next two years will raise the inventory to

617 units fielded with EOD and SPECWAR teams. The current contract cost is $32,000 per unit; about $20,000,000 total.

An Operations Support Kit (OSK) containing test equipment and an inventory of repair parts to support deployed operations is procured in the same contract. EOD issues one OSK to each group of four MK 16. SPECWAR uses one OSK for five MK 16. There will be approximately 125 OSK in the field by the end of 1996 at a cost of about $32,000 each, $3,750,000 total.

The MK 16 is a critical system in the growing concern of MCM and SPECWAR diving operations. As MK 16 procurement continues, repair parts management will become more critical to the readiness of the deployed detachments and to the budgets of the parent commands.

### 4. MK 16 Operations

MK 16-equipped EOD Dets are configured, (the number of divers and MK 16), by their parent commands to match the mission. The US Navy Diving Manual (p. 15-12) sets the lowest number of MK 16 for MK 16 required missions at two. A single, tended diver can conduct underwater operations while the second diver stands by ready to deploy in emergency. Although unlikely in operational scenarios, the standby diver could use other diving equipment (SCUBA) if the operation that the primary diver is involved in does not require the MCM characteristics of MK 16 and does not exceed the depth limits of the standby's equipment.

Many EOD commands prefer the option of using two divers working underwater as a team, with a third diver as the standby diver. It is unusual to use more than two divers in the water at the same time other than in training situations. With three then established as the mission essential minimum of operational MK 16, additional MK 16 are routinely deployed in combinations of ready service spares (RSS) and spares in lay-up.

The ready service spare is used universally as an on-scene replacement for a malfunctioning MK 16. The RRS is assembled and tested at the beginning of the diving day along with those that will be the primary and standby diver's MK 16. All four MK 16 will be stationed at the dive site for immediate use during the operation. The RSS will not normally be used unless one of the other three MK 16 fails.

Any spares in addition to the three MK 16 in use and the fourth as a RRS are maintained in a lay-up status at the maintenance facility along with the inventory of repair parts. If a failure occurs during the diving day, repairs are conducted at the end of the day when the divers return to the maintenance facility.

When MK 16 fails, EOD Dets follow this general decision tree to resolve the failure:

1. If repair parts are in-stock and the repair is not extensive, repairs are made immediately. The failed MK 16 is returned to a ready status, and any repair parts used are immediately reordered.

2. If repair parts are in-stock but the repair is extensive and not practical to accomplish before the next required mission, check to see if there is a spare in lay-up.

3. If there is a spare in lay-up, bring it to a ready status. Repair the down MK 16 at the earliest opportunity and immediately reorder parts.

4. If there is no spare in lay-up, delay the mission until repairs can be accomplished, or attempt the mission without the fourth MK 16 as RSS.

5. If the repair parts are not in-stock, check to see if there is a spare in lay-up. If there is a spare in lay-up, bring the spare to a ready status and order the repair parts through normal supply priorities (a CASREP is not permitted).

6. If there is no spare in lay-up, order the repair parts along with a CASREP reporting decreased

mission readiness, and delay the mission until repairs can be accomplished, or attempt the mission without the fourth MK 16 as RSS.

A CASREP status of less than fully mission capable would be justified only if less than four MK 16 were fully functional. So long as failures were supported by the repair parts inventory and spare MK 16 were available when the inventory did not support the failure, no CASREP would be generated.

## B. THE SPCC MODEL

### 1. Computation Model Determination

The methods SPCC uses at provisioning conferences, and as described below, are simplified versions of a more complex computer program, the Fleet Logistics Support Improvement Program (FLSIP), but result in quantities very near the ultimate computed quantity listed in the APL. (SPCCINST 4400.30c) By limiting the process description to the case of MK 16, several complications that affect other systems can be eliminated. Minimum replacement unit (MRU), planned maintenance requirement (PMR), and technical overrides (TOR) are not involved with the MK 16 computation and can be overlooked. MRU represents the minimum number of the repair parts required to accomplish a repair: for MK 16, all MRU are one. There are no PMR, indicating that parts are not normally required for planned maintenance. Also, there are no TOR, indicating there are no technical decisions that would override the quantities computed.

The inputs required to determine quantity are:

- POP: Number of MK 16 assigned multiplied by the number of that component in one MK 16.

- MCC: Mission Criticality Code. The importance of the MK 16 to the (EOD/USN) mission.

- MEC: Military Essentiality Code. The importance of each repair part to the operation of the MK 16. Repair part MEC 1 = essential, MEC 3 = not essential.

- BRF: Best Replacement Factor. BFR = 0.03 means 3 out of 100 will fail in one year. Computed from actual fleet demand.

- Demand Based Item: Expected demand is at least one in 90 days.

- Insurance Item: Expected demand is less than one in 90 days but item is required because of high MEC and/or MCC.

BRF is developed from the initial Technical Replacement Factor (TRF) estimated by the manufacturer during procurement. Once repair parts are provisioned based on TRF, the value is continuously modified based on actual demand from the fleet. This demand includes all manner of consumption of the repair parts: actual failure, loss in shipping, theft, incorrect maintenance, etc. A two year demand development period (DDP) is the target for complete transition from TRF to BRF. (OPNAVINST 4423.5, Encl. 4, p. 1) With the POP determined quantitatively and BRF determined statistically, SPCC needs determination by the field engineering service activity of MCC and MEC. MK 16 has been assigned a MCC of 3, where 1 is the lowest and 4 equates to capital ships and nuclear submarines. The MEC for all MK 16 repair parts is either 1 or 3, where 1 is essential and 3 is not essential. Our primary concern is with those parts deemed essential to the operation of the MK 16, thus non-essential parts will not be considered in this thesis. This input of MEC = 1 and MCC = 3 is then applied to the Mission Criticality Code Matrix provided by Navy Fleet Material Support Office (FMSO) to arrive at a final computed MCC = 3. The computed MCC value, 3, permits APL quantities to be derived from Table IA or Table II: MODFLSIP located in SPCCINSTRUCT 4400.30, p. 1D3-31) (computed MCC 1 or 2 uses

FLSIP). Both SPCC Table IA and II provide similar results. The significant difference is that Table IA uses annual replacement factor on the Y-axis and POP on the X-axis where Table II uses a formula that corrects the annual replacement factor for quarterly demand and POP:

> (BRF * POP)/4 = 90-day expected demand (SPCC Table II Factor). SPCC Table II is based on 90-day expected demand and is converted to the quantity allowance.

MODFLSIP identifies both demand based items and insurance items (quantities marked with * on the APL). For demand items, enter the SPCC Table II with a 90-day expected demand greater than 1:

> (BRF * POP)/4 > 1, enter SPCC Table II with this factor: example, Factor = 1.9, APL quantity allowance = 4.

Insurance items are those critical parts (MEC 1) that are permitted under MODFLSIP guidelines when the SPCC Table II factor is less than 1.00. Insurance items are provided to protect against failures when demand history is uncertain and for failures that might occur as the system ages. If the 90-day expected demand is less than 0.025, no parts are authorized; in the range of 0.025 to 0.49, and if the item is considered an insurance item, then the APL quantity is one. If the 90-day expected demand is 0.50 to 0.999, the APL quantity is two. Beyond 0.999, the item is defined as a demand item.

### 2. Current MK 16 Protection Level Determination

FLSIP and MODFLSIP Models are based on the Poisson distribution and provide an advertised 90% protection against stockout of any single item over a 90-day period. (SPCC 4400.30C, p. 1D3-33) The protection level is actually a

minimum of 90% for APL (1), (2), (3), and (4) columns and is about 90% for the mean number of systems for the other columns. In all cases the protection level is not uniform for all expected demands. A uniform protection level would only be possible if repair parts were able to be issued in less than whole units. Figure 2.3 shows the protection level as over 0.98 for items with an expected demand of less than 0.025. This interprets as those items with a small demand will likely not be demanded over the 90-day period. At an expected demand of 0.025, the MODFLSIP permits one repair part (for those parts considered critical). This level of coverage provides a protection level exceeding 0.99. From this point on the graph, the protection level drops as the expected demand increases until the model allows an additional repair part at an expected demand of 0.50. With the extra repair part, protection level climbs to over 0.985 from a low of about 0.935. This cycle repeats itself with each additional discrete repair part authorized.

The SPCC MODFLSIP Table II also lists the number of repair parts authorized for demand based items. Regardless of MEC, a 90-day expected demand of 1.00 or more is authorized at least 2 repair parts. Items with the expected demand less than 1.00 are reviewed for MEC. This thesis focuses on only vital parts, MEC = 1. Repair parts with MEC = 1 but with a 90-day expected demand of less than 1.00 but more than 0.025 are authorized as insurance items. Figure 2.3 shows a significantly greater protection against stockout for these insurance items (0.995 to 0.999 for insurance items and 0.907 to 0.995 for demand items). All but thirteen O-Level repair parts for an EOD Det with four MK 16 are insurance items.

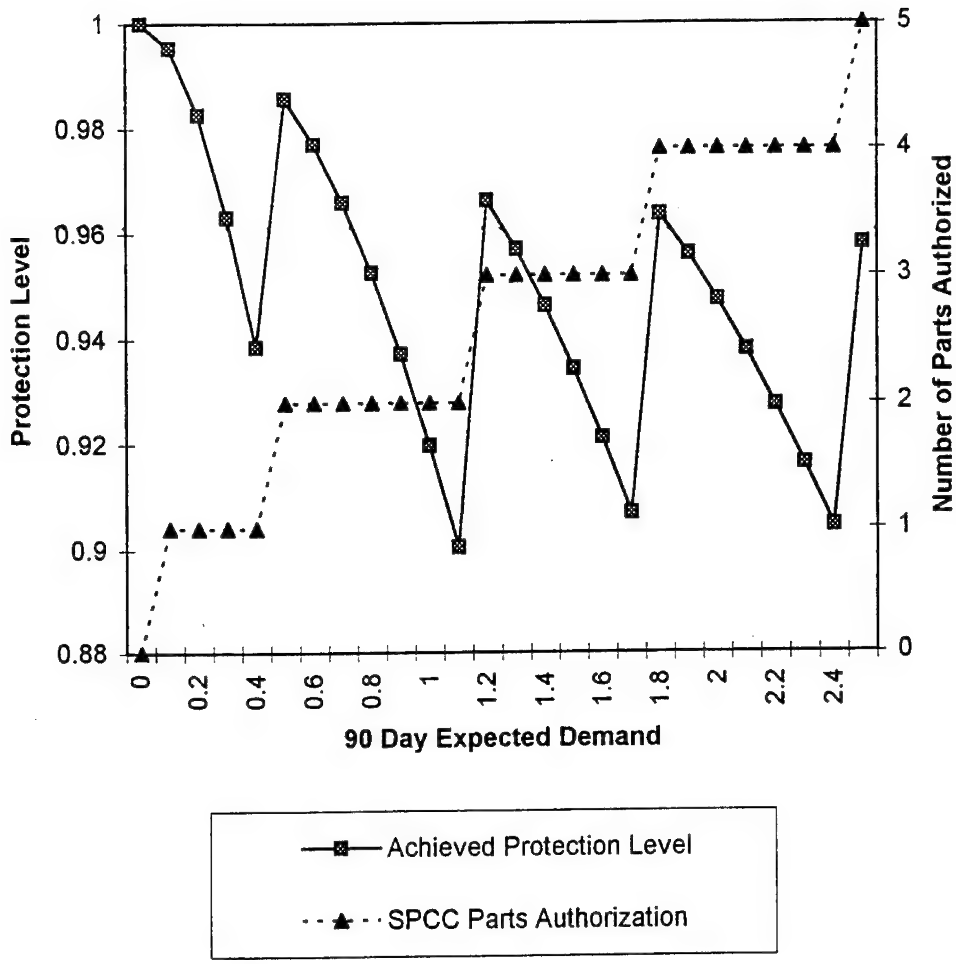


Figure 2.3 SPCC Parts Authorization Protection Level for 90-Day Expected Demand to Support One Item.

Some assumptions implied by the APL quantities directly affect the accuracy of the protection levels derived from the 90-day expected demand figures:

1. The demand figures from the fleet require prompt reordering to be reflected in BRF. When parts stockpiles are allowed to be depleted and not reordered because of budget constraints, the input to SPCC indicates an inaccurate picture of demand for the repair part. Waiting for a new fiscal year's funding might show zero demand for more than one fiscal quarter. The initial spares provided in the OSK could dramatically reduce the apparent demand if not kept restocked as originally issued.

2. The 90-day expected demand calculation is based on the cold war assumption that a major conflict would cause gaps in our supply lead times of as many as 90 days. APLs were designed to provide all the parts required for operations during this 90-day lead time with a 90% in-stock probability planned for each part. With the close of the cold war and the likelihood of speedy resupply by air and sea this lead time is probably closer to 30 to 60 days.

3. The 90-day expected demand was also based upon historical usage. In the recent history of the US Navy since the introduction of MK 16, high OPTEMPO calendar quarters that reflect wartime demands have not been common. Peacetime demands reflect an average MK 16 usage of 15 to 25 days per quarter. During Desert Storm, one EOD Det dove over 70 days in one quarter. However, this high usage gets lost when averaged with the typical peacetime demands. Unlike the systems of typical fleet units, the MK 16 is used intermittently for training until major exercises and Desert Storm scenarios develop. When an EOD Det packs up for war, which expected demand should they anticipate?

### 3. 0.5 + FLSIP

SPCC recently introduced a new model for APL calculations that takes advantage of the decreased resupply lead times expected post-cold war. In the 0.5+ FLSIP model, the level of

insurance for critical items is reduced. Where MODFLSIP allowed one repair part if the 90-day expected demand was 0.025 to 0.49 and two repair parts for 0.50 to 1.00, the 0.5+ FILSIP permits one repair part for a 90-day expected demand of 0.125 to 1.00. To compensate for this dramatic reduction in insurance items, SPCC uses a combination of 3M and CASREP data to create demand selection rules that add back allowance items that increase protection level at the least cost. (Eggenberger, p. 13) In addition to adding back some items, those items removed from O-Level inventories are to be consolidated at shore based facilities that could expedite resupply with a reduced lead time.

#### 4. The Impact Of MK 16 Spares

As described in the Introduction, it is common for EOD Dets to deploy with additional MK 16 in lay-up for use in emergency. This emergency could be in the form of:

- Repair parts not in-stock to repair a down MK 16.
- Repair parts in-stock but mission requirements do not permit immediate repair.
- The repairs are beyond the capability of the unit.

When the spare MK 16 is taken out of lay-up and the down MK 16 is taken out of service, the spare can be viewed in a variety of ways. First, the spare is truly only a box of repair parts that happen to be one MK 16 when assembled. In this form the spare is available for cannibalization but is usually used as a full-up replacement for the down MK 16. This then makes the down rig available for cannibalization, with the exception of the failed part. Cannibalization is common when operational units are faced with the alternative of cancelling a mission. Officially, cannibalization is prohibited and it may have further detrimental effects on the system. (Blanchard, 1992, p. 335) Second, the entire spare

MK 16 is acting only as the single part that was required to fix the other MK 16; that is, the entire $42,000 spare MK 16 was held in lay-up to protect against a stockout of what might have been an inexpensive repair part.

The policies of SPCC, and those of the individual inventory managers, are compromises that hope to reach an optimal solution in the face of a wide variety of constraints that change from month to month. The proposed spreadsheet model provides a tool to deal with these rapidly changing demands. In Chapter III, we will present the methodology of a basic spreadsheet decision support tool that will help inventory managers relate these varied constraints and respond to future changes as soon as they are known.

# III. SPREADSHEET DECISION SUPPORT MODEL

## A. INTRODUCTION TO SPREADSHEETS

Vazsonyi (1993) well states the advantages and the potential of spreadsheets. We have used his thoughts throughout this section while adapting them more specifically to this case.

One of the tenets of W. E. Demming is that no matter how dedicated, the worker cannot produce quality that on the average exceeds the quality of what the process is capable of producing (Heizer, 1993, p. 738). This focus on improving the process has contributed to the growth of Management Sciences/ Operation Research (MS/OR) techniques and models. MS/OR rely upon a variety of mathematical, statistical and many other analytical tools in an inter-disciplinary approach to process improvement (Heizer, 1993, p. 4). The major barrier to the incorporation of MS/OR is the lack of command and operations level personnel comfortable with algebra, classical mathematics, and probabilities. Spreadsheets build the bridge between MS/OR and the user. Spreadsheets are the easiest, most powerful, and general purpose management tools available for doing basic numerical analysis. Their power is reflected most in the ability the user gains in proposing "what if" scenarios. Given a scenario as in the MK 16 inventory model with five variables and over 100,000 possible combinations, entering the complex formula long hand becomes a tremendous though not impossible chore. A spreadsheet consolidates the multiple mathematical steps required and updates all of the dependent (outcomes) variables automatically when one of the input parameters is changed. This ability to experiment, by changing the input and seeing the effect immediately, helps the user develop an intuitive feel for the relationships between the inputs and output.

SPCC's spreadsheet equivalent converts the outputs of their complex and dynamic mathematical model into tables like the APL. However, once committed to hardcopy, the model looses its flexibility and becomes two-dimensional: we enter the appropriate column for the number of MK 16 assigned (input), move our finger down to the line of the repair part in question, and receive the number of repair parts authorized (outcome). SPCC's compromise can only be improved upon with the advent of the widespread use of personal computers and spreadsheets than can be customized for the individual requirements of a command.

## B. METHODOLOGY FOR THE MK 16 REPAIR PARTS SPREADSHEET

We have selected 78 repair parts that cover over 80% of the inventory costs; this allows us to narrow the scope from the total 184 critical parts identified in the APL (See Table 3.1.) This allows us to focus on those items that are the greatest burden to a command's budget. Additionally, the repair parts have been tailored to these criteria:

- No consumables, like sensors or pads, and no parts that might be viewed as repair parts yet are employed operationally, like $HeO_2$ vessels.
- All have a history of demand with SPCC.

The 78 repair parts selected for evaluation cover most of the items costing more than $20.00. The most costly items cost more than $6,000.00. A selection of these repair parts in quantities recommended by SPCC for an EOD Det with four MK 16 costs $46,131; $51,201 for a EOD MU with nine to twenty MK 16.

Table 3.1 List of MK 16 MOD O Repair Parts Selected for Review.

| Item # | DWRG # | Selected Repair Parts (Ranked by Demand) NIIN | Item Name | Unit Price | Annual Demand BRF | POP In Single Eqpt | Annual Demand Per Eqpt | APL Auth for Column 4 | 5-8 | 9-20 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6196125- | M5340-01-298-3012 | CATCH, CLAMPING | $ 23.00 | 0.55 | 2 | 1.1 | 2 | 4 | 7 |
| 2 | 6196133 | M5310-01-297-5909 | GASKET, HOSE CONN | $ 4.80 | 0.51 | 2 | 1.02 | 2 | 4 | 6 |
| 3 | 6195857 | M4240-01-298-3005 | INLINE FILT ASSY | $ 254.00 | 0.375 | 2 | 0.75 | 2 | 3 | 5 |
| 4 | 6196137 | M4730-01-296-5863 | CLAMP, HOSE NO 1 | $ 11.50 | 0.225 | 2 | 0.45 | 1 | 2 | 3 |
| 5 | 6196138 | M4730-01-297-0908 | CLAMP, HOSE NO 2 | $ 11.50 | 0.225 | 2 | 0.45 | 1 | 2 | 3 |
| 6 | 6196132 | M4720-01-297-5982 | HOSE, AIR BREATHING | $ 9.00 | 0.15 | 2 | 0.3 | 1 | 2 | 3 |
| 7 | 6196159 | H6685-01-297-0965 | OX HI PRESS GAGE ASSY | $ 1,430.00 | 0.275 | 1 | 0.275 | 1 | 1 | 2 |
| 8 | 6195775 | M5305-01-296-5797 | SCREW, MACH, BLEED | $ 17.50 | 0.08 | 3 | 0.24 | 1 | 1 | 2 |
| 9 | 6196127 | M4820-01-298-3011 | VALVE CHECK | $ 10.50 | 0.225 | 1 | 0.225 | 1 | 1 | 2 |
| 10 | 6195844 | M5360-01-298-2994 | SPRING, HLCL, CPRSN | $ 6.90 | 0.048 | 4 | 0.192 | 1 | 1 | 2 |
| 11 | 6195843 | M5305-01-299-9746 | SCREW, SHOULDER | $ 11.00 | 0.048 | 4 | 0.192 | 1 | 1 | 2 |
| 12 | 6196109 | M4730-01-297-5960 | FITTING, FEMALE | $ 92.00 | 0.06 | 2 | 0.12 | 1 | 1 | 1 |
| 13 | 6196109 | M4730-01-297-5960 | FITTING, FEMALE | $ 92.00 | 0.06 | 2 | 0.12 | 1 | 1 | 1 |
| 14 | 6195802- | M5305-01-296-5799 | SCREW, MACH,PHD #6 | $ 3.70 | 0.005 | 21 | 0.105 | 1 | 1 | 1 |
| 15 | 6195797 | H5915-01-296-5892 | CENTER SECTION | $ 4,060.00 | 0.1 | 1 | 0.1 | 1 | 1 | 1 |
| 16 | 6195764 | H5935-01-295-9130 | CONN HSG ASSY ELEC | $ 2,480.00 | 0.1 | 1 | 0.1 | 1 | 1 | 1 |
| 17 | 6195886 | M4820-01-295-9266 | DIAPHRAM | $ 76.00 | 0.1 | 1 | 0.1 | 1 | 1 | 1 |
| 18 | 6196146 | M5340-01-297-0909 | CLAMP, LOOP ASSY | $ 19.00 | 0.095 | 1 | 0.095 | 1 | 1 | 1 |
| 19 | 6196080 | M5935-01-295-9129 | BATT CONT BRD ASSY | $ 37.00 | 0.09 | 1 | 0.09 | 1 | 1 | 1 |
| 20 | 6195802- | M5305-01-296-5800 | SCREW, MACH,PHD #6 | $ 3.70 | 0.005 | 18 | 0.09 | 1 | 1 | 1 |
| 21 | 6195942 | M5305-01-295-9121 | SCREW, MACH, PNH | $ 3.70 | 0.01 | 8 | 0.08 | 1 | 1 | 1 |
| 22 | 6196119 | M5340-01-296-5904 | VALVE, HANDWHEEL | $ 22.50 | 0.038 | 2 | 0.076 | 1 | 1 | 1 |
| 23 | 6196012 | H8120-01-297-0901 | DIL VALVE ASSY | $ 1,810.00 | 0.035 | 2 | 0.07 | 1 | 1 | 1 |
| 24 | 6195981 | M4710-01-300-9986 | TUBE ASSY, INL FIL-T | $ 298.00 | 0.035 | 2 | 0.07 | 1 | 1 | 1 |
| 25 | 6195807- | H5980-01-297-0920 | SECONDARY DISP ASSY | $ 4,060.00 | 0.068 | 1 | 0.068 | 1 | 1 | 1 |
| 26 | 6196066 | M5961-01-297-0949 | PRI DISPLAY ASSY | $ 495.00 | 0.06 | 1 | 0.06 | 1 | 1 | 1 |
| 27 | 6196140 | M4820-01-298-2826 | VALVE, CHECK ASSY | $ 1,234.00 | 0.058 | 1 | 0.058 | 1 | 1 | 1 |
| 28 | 6196097- | H4820-01-295-9157 | REG DIL ASSY | $ 2,040.00 | 0.055 | 1 | 0.055 | 1 | 1 | 1 |
| 29 | 6195849 | H4820-01-295-9158 | OXY REG MTD ASSY | $ 2,040.00 | 0.055 | 1 | 0.055 | 1 | 1 | 1 |
| 30 | 6195977 | H4820-01-295-9155 | DIL REG ASSY | $ 1,600.00 | 0.055 | 1 | 0.055 | 1 | 1 | 1 |
| 31 | 6195978 | H4820-01-295-9156 | OXY REG ASSY | $ 1,600.00 | 0.055 | 1 | 0.055 | 1 | 1 | 1 |
| 32 | 6195965- | H4820-01-299-9859 | BYPASS VALV ASSY DIL | $ 606.00 | 0.055 | 1 | 0.055 | 1 | 1 | 1 |
| 33 | 6195975 | M4820-01-296-5887 | BODY, VALVE SUBASSY | $ 49.00 | 0.018 | 3 | 0.054 | 1 | 1 | 1 |
| 34 | 6195836 | H4820-01-299-9860 | BYPASS VALV ASSY OXY | $ 736.00 | 0.05 | 1 | 0.05 | 1 | 1 | 1 |
| 35 | 6196121 | M5340-01-297-5955 | LID, CANISTER | $ 164.00 | 0.05 | 1 | 0.05 | 1 | 1 | 1 |
| 36 | 6195837 | M5305-01-296-5801 | SCREW, MACH | $ 3.70 | 0.005 | 10 | 0.05 | 1 | 1 | 1 |
| 37 | 6196102 | H5998-01-297-0946 | PRI ELECTRONIC DISP | $ 6,390.00 | 0.048 | 1 | 0.048 | 1 | 1 | 1 |
| 38 | 6196108 | M5305-01-296-5796 | SCREW, MACH,FH.82#6 | $ 3.70 | 0.005 | 9 | 0.045 | 1 | 1 | 1 |
| 39 | 6196101 | H4810-01-297-5976 | OXY ADDITION VALVE | $ 6,010.00 | 0.04 | 1 | 0.04 | 1 | 1 | 1 |
| 40 | 6195802- | H4820-01-297-5977 | OXY VALVE REG | $ 1,050.00 | 0.04 | 1 | 0.04 | 1 | 1 | 1 |
| 41 | 6195762 | M5340-01-296-5838 | WAIST STRAP ASSY RT | $ 396.00 | 0.04 | 1 | 0.04 | 1 | 1 | 1 |
| 42 | 6195814- | M5340-01-299-9780 | COVER ASSY | $ 375.00 | 0.04 | 1 | 0.04 | 1 | 1 | 1 |
| 43 | 6195807- | M5340-01-299-9781 | WAIST STRAP ASSY LEFT | $ 369.00 | 0.04 | 1 | 0.04 | 1 | 1 | 1 |
| 44 | 6196153 | M5340-01-297-0986 | SHOULD STRAP LEFT | $ 111.00 | 0.04 | 1 | 0.04 | 1 | 1 | 1 |

## Table 3.1 (Continued)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | 6196011 | H5935-01-296-5829 | FLTG, BHD, ASSY, ELEC | $ | 706.00 | 0.035 | 1 | 0.035 | 1 | 1 | 1 |
| 46 | 6195997 | M4710-01-297-0924 | TUBE ASSY | $ | 497.00 | 0.035 | 1 | 0.035 | 1 | 1 | 1 |
| 47 | 6196126 | M4710-01-297-0995 | TUBE ASSY, DIL REG | $ | 478.00 | 0.035 | 1 | 0.035 | 1 | 1 | 1 |
| 48 | 6195996 | M4710-01-297-0994 | TUBE ASSY, FL CTRL, OX | $ | 397.00 | 0.035 | 1 | 0.035 | 1 | 1 | 1 |
| 49 | 6195998 | M4710-01-297-0997 | TUBE ASSY, DIL BP SC | $ | 396.00 | 0.035 | 1 | 0.035 | 1 | 1 | 1 |
| 50 | 6195802- | M4710-01-297-0991 | TUBE ASSY, DIL REG TO | $ | 350.00 | 0.035 | 1 | 0.035 | 1 | 1 | 1 |
| 51 | 6195767 | M4710-01-297-0998 | TUBE ASSY, DIL S T T S | $ | 350.00 | 0.035 | 1 | 0.035 | 1 | 1 | 1 |
| 52 | 6195991 | M4710-01-297-0999 | TUBE ASSY, DIL S T TO | $ | 342.00 | 0.035 | 1 | 0.035 | 1 | 1 | 1 |
| 53 | 6195987 | M4710-01-297-0992 | TUBE ASSY DIL S TEE D | $ | 315.00 | 0.035 | 1 | 0.035 | 1 | 1 | 1 |
| 54 | 6195986 | M4710-01-297-0993 | TUBE ASSY OX S T OX | $ | 174.00 | 0.035 | 1 | 0.035 | 1 | 1 | 1 |
| 55 | 6195988 | M5310-01-297-0889 | NUT, ACORN | $ | 5.80 | 0.005 | 7 | 0.035 | 1 | 1 | 1 |
| 56 | 6195983 | M1386-01-304-7142 | MOUTHPIECE | $ | 1,560.00 | 0.031 | 1 | 0.031 | 1 | 1 | 1 |
| 57 | 6195989 | M5325-01-297-0899 | GROMMET, NONMETALLI | $ | 11.00 | 0.01 | 3 | 0.03 | 1 | 1 | 1 |
| 58 | 6195990 | M4710-01-296-5981 | TUBE ASSY, DIL ADD | $ | 148.00 | 0.028 | 1 | 0.028 | 1 | 1 | 1 |
| 59 | 6195984 | M5305-01-296-5812 | NUT, JAM SMALL PATTER | $ | 5.80 | 0.005 | 5 | 0.025 | 0 | 1 | 1 |
| 60 | 6195985 | M6150-01-297-0903 | CABLE ASSY, PRIMARY | $ | 722.00 | 0.02 | 1 | 0.02 | 0 | 1 | 1 |
| 61 | ~~6195815-~~ | ~~M4240-01-297-5994~~ | ~~CANISTER ASSY~~ | $ | 709.00 | 0.02 | 1 | 0.02 | 0 | 1 | 1 |
| 62 | 6195906- | M4820-01-297-5968 | SEAT, VALVE | $ | 180.00 | 0.02 | 1 | 0.02 | 0 | 1 | 1 |
| 63 | 6195947 | M1386-01-295-9261 | SEAT, HELIC | $ | 24.00 | 0.02 | 1 | 0.02 | 0 | 1 | 1 |
| 64 | 6196166 | M5340-01-297-0985 | CAP, SECONDARY DISP | $ | 22.50 | 0.02 | 1 | 0.02 | 0 | 1 | 1 |
| 65 | 6196123 | M5920-01-304-6745 | FUSEHOLDER | $ | 6.20 | 0.02 | 1 | 0.02 | 0 | 1 | 1 |
| 66 | 6196122 | M5305-01-296-5805 | SCREW, MACH,FH.820 | $ | 4.20 | 0.005 | 4 | 0.02 | 0 | 1 | 1 |
| 67 | 6196006 | M5310-01-298-2807 | NUT, PLAIN, HEX | $ | 5.80 | 0.005 | 4 | 0.02 | 0 | 1 | 1 |
| 68 | 6195817- | M5310-01-297-0890 | NUT, SECONDARY DISPL | $ | 61.00 | 0.015 | 1 | 0.015 | 0 | 1 | 1 |
| 69 | 6196120 | M5365-01-300-0091 | RING, RETAIN, THRD UPP | $ | 28.50 | 0.015 | 1 | 0.015 | 0 | 1 | 1 |
| 70 | 6196019 | M4820-01-298-2862 | RETAINER, D:PLATE BASE | $ | 163.00 | 0.01 | 1 | 0.01 | 0 | 0 | 1 |
| 71 | 6196095 | M5975-01-295-9251 | COVER, BATT ASSY | $ | 73.00 | 0.01 | 1 | 0.01 | 0 | 0 | 1 |
| 72 | 6196017 | M4220-01-297-6006 | BODY, VALVE | $ | 7.50 | 0.01 | 1 | 0.01 | 0 | 0 | 1 |
| 73 | 6195924 | M5360-01-297-6097 | SPRING, COMPRESSION | $ | 5.00 | 0.01 | 1 | 0.01 | 0 | 0 | 1 |
| 74 | 6195922 | M4820-01-298-2860 | BUTTON ASSY, OXY | $ | 78.00 | 0.01 | 1 | 0.01 | 0 | 0 | 1 |
| 75 | 6196073 | M4820-01-298-2861 | BUTTON ASSY, DIL | $ | 78.00 | 0.01 | 1 | 0.01 | 0 | 0 | 1 |
| 76 | 6195862 | M5305-01-296-5803 | SCREW, MACH, MNH#10 | $ | 3.70 | 0.005 | 2 | 0.01 | 0 | 0 | 1 |
| 77 | 6196163 | M6150-01-297-0904 | CABLE ASSY, O2 VALVE | $ | 456.00 | 0.009 | 1 | 0.009 | 0 | 0 | 1 |
| 78 | 6195809- | M5340-01-295-9268 | SUPPORT BASE ASSY | $ | 164.00 | 0.005 | 1 | 0.005 | 0 | 0 | 0 |

## C. INPUTS TO THE SPREADSHEET

### 1. Population: "Number of MK 16 (active)"

For the APL, SPCC uses the repair part's 90-day expected demand to generate the quantities authorized for 1, 2, 3, 4, 5-8, 9-20, and 21-50 populations. As an example, the APL Listing for a retainer pin is provided in Figure 1.1.

By adding a fifth MK 16, a 25% increase in systems, the inventory of retainer pins had to be increased from six to ten, a 66% increase in costs. A protection level identical to that for four MK 16 might be achieved with only one additional part. The jump from six retainer pins to ten was to permit grouping of the systems. The number of systems are grouped to permit quick approximate calculations without an unwieldy document that lists the quantity individually for each of one to fifty systems. Instead, with 10 parts authorized, those commands with five MK 16 have a much higher protection level than the commands with eight MK 16, though their costs are the same. This difference is more pronounced in the APL (9-20) column. Figure 3.1 displays the relationship between the protection levels, provided by an inventory based on the APL (9-20) column, that an EOD MU would experience as the number of assigned MK 16 increases. The EOD MU with nine MK 16 maintains an average protection level of 0.993 with no repair part at less than 0.970; well above the SPCC goal of 0.900. As the number of assigned MK 16 increases to twenty the protection drops to an average of 0.956. More important, the minimum protection level within the inventory has dropped to 0.758; several of the high demand items are significantly below the SPCC goal.

Another assumption supporting the grouping of the larger populations of systems is the likelihood of redundant systems. If an EOD MU with twenty MK 16 routinely held several in lay-up, the protection provided by the APL (9-20) column could be adequate.

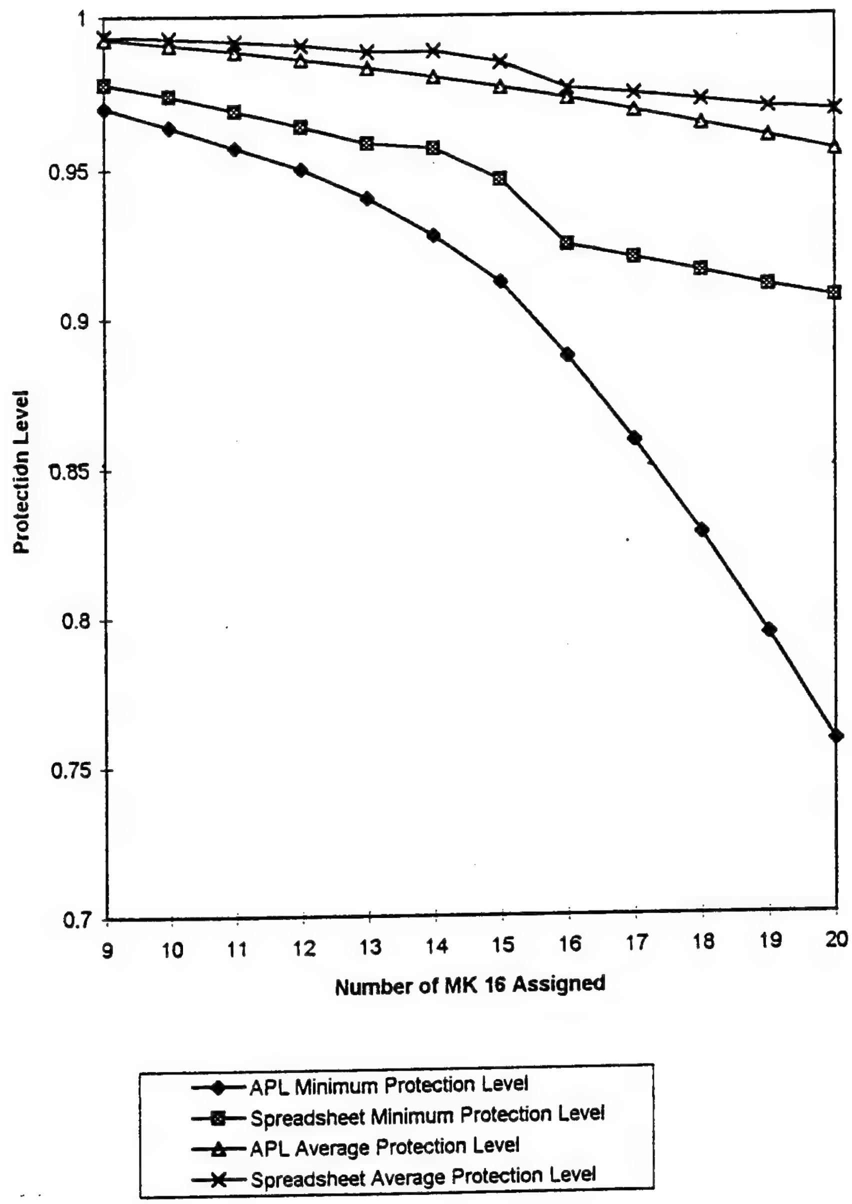


Figure 3.1 Comparison of Protection for the APL (9-20) Column and the Spreadsheet Model Inventory as the Number of MK 16 Assigned Changes from 9 to 20 (Spreadsheet Costs ≤ APL Costs).

With the proposed spreadsheet model the incremental calculation is quick and exact in increments of one; this avoids the dilemma of the inventory manager on the cusp of a grouping. Additional, the spreadsheet permits the calculation to be made based on the exact number of active MK 16 and not on approximations.

The calculation for the spreadsheet that allows the exact number of repair parts to be generated for the number of MK 16 maintained is:

BRF * POP in one MK 16 * Number of MK 16 (active)

The number of repair parts in one MK 16 is carried with each repair part's description and is included automatically when the repair part is reviewed for BRF. The BRF is from SPCC and the "Number of MK 16 (active)" is inputted by the operator from the spreadsheet's Control Panel screen. (See sample spreadsheet Control Panel in Figure 3.2). The inventory manager must only determine how many MK 16 will be supported by this inventory. Two detachments deploying together with the same task should not use their aggregate

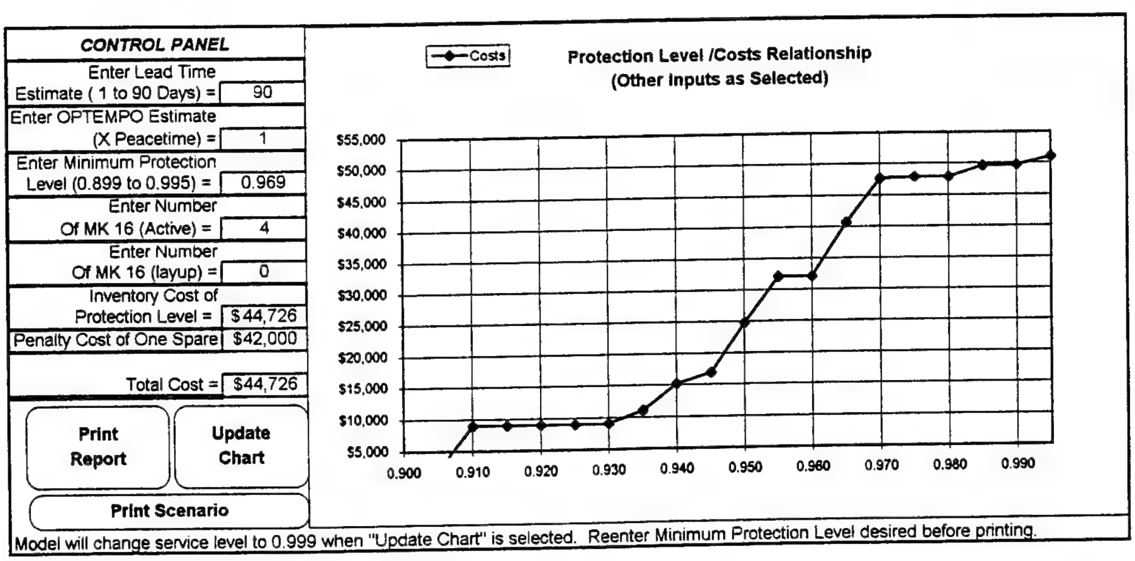


**Figure 3.2 View of Spreadsheet Control Panel.**

population unless their is no chance that the inventory might need to be split.

### 2. Spares: "Number of MK 16 (in lay-up)"

The actual cost of a single MK 16 that a command would use as spare in lay-up for a deployment is difficult to include as a cost of inventory. Given that the quantity of MK 16 issued to each command is determined and funded at a higher level, the cost to the command is negligible when compared to supporting a $100,000 repair parts inventory and its associated holding costs. An EOD Det can eliminate the need for an inventory if there are enough MK 16 as spares in lay-up. If lead times are short enough and OPTEMPO was low, a single spare MK 16 could substitute for a down MK 16 until the repair part was received through the supply pipeline: no repair parts inventory would be required. This would be a more valid assumption if cannibalization was intended. The down MK 16 becomes the inventory of repair parts with each cannibalized repair part immediately reordered. The primary goal is to have four fully operational MK 16, but a secondary goal would be to repair the down MK 16. The presence of inactive or spare MK 16 is not assumed by the SPCC model in determining POP and BRF, but is assumed in the grouping of systems in APL columns (5-8) and (9-20). The proposed spreadsheet model can simulate the effect of spare MK 16 by entering the number of spares in the "Number of MK 16 (in lay-up)" block. Each spare indicated reduces the number of inventory parts required by one each. This implies perfect cannibalization and lacks any true cost penalty. The "Cost of One MK 16" can be changed as the inventory manager wishes to reflect actual replacement cost or other penalty costs. The equation that incorporates the penalty cost as a cost of inventory is:

(Cost of One MK 16 * Number in lay-up) + (Inventory Cost of Protection Level) = Total Cost

### 3. Lead Time

The lead time assumed by the SPCC MODFLSIP model is 90 days. The formula used in the spreadsheet provides the inventory manager the flexibility to change this to match various scenarios and then see the effects of the change on protection level, cost, and the mix of parts required. The inventory manager can provision the EOD Det for a full six month deployment expecting no resupply, or support a detachment with access to overnight delivery service.

The APL figures are generated by dividing the annual demand BRF by four to arrive at a figure that reflects a 90-day demand.

90-day Expected Demand = (BRF * POP)/4

To allow the flexibility to find the demand for any selected time period, the number of days estimated by the inventory manager, "Enter Lead time Estimate," is divided by 365 and then multiplied by the annual BRF.

Expected demand in *n* days = (BRF * POP * *n*)/365

### 4. OPTEMPO

The demand SPCC recognizes for a repair part is directly tied to the number of repair parts ordered per quarter. MK 16 repair parts usage is averaged over ten quarters. High order rates, because of changes to ordering practices or wartime usage, are smoothed with low OPTEMPO peacetime operations. An inventory manager provisioning for Desert Storm may want to reflect a higher OPTEMPO. Because SPCC is looking at a fleet-wide demand, comparing one command's OPTEMPO to that of the fleet may not be completely proportional. Although one command may typically operate their twenty MK 16 only five or six days each per month, a training command may operate all twenty MK 16 fifteen days per month. Once the inventory manager is comfortable with the estimated OPTEMPO, it must be

converted into a proportion of SPCC's ten-quarter average OPTEMPO. If the estimate is that the EOD Det will be operating at four times the normally expected OPTEMPO, enter four in "Enter OPTEMPO Estimate," one-half the normal fleet OPTEMPO, enter 0.50. This formula ties OPTEMPO into the BRF calculation:

Expected demand in $n$ days adjusted for OPTEMPO =
(BRF * POP * Enter OPTEMPO Estimate * $n$)/365

### 5. Protection Level

The protection level in some models is the function of the inputs rather than being one of the inputs. The proposed spreadsheet model allows the user to approach from two ways. If the user wishes to commit to a particular service level for the sake of consistency or to document the limitations of the budget, the protection level can be entered as such. A second approach available is to graph all the possible protection levels against the costs for each, based upon the other selected inputs. An example would be: given the inputs selected for 90-day lead time, OPTEMPO = 2, four active and no lay-up MK 16, what is the graphic trade-off between protection level and costs? This is described in greater detail under "Outputs."

## D. OUTPUTS

### 1. "Inventory Cost of Protection Level"

The spreadsheet's Control Panel provides the user with the ability to build a scenario and immediately view the results. After inputting the "Minimum Protection Level," "OPTEMPO," "Number of MK 16 (active)" and "Number of MK 16 (in lay-up)," the user can select a protection level and see the resultant "Total Cost." By clicking on "Update Chart" the user can see a graphic representation of the relationship between the range of protection levels from 0.895 to 0.995 and

the associated costs. The user can then select from the graph the protection level where the marginal gain in protection level is most favorable within the budget constraints prescribed to get the exact cost of that protection. The Control Panel graph in Figure 3.1 is automatically generated within the spreadsheet based upon inputs displayed (all protection levels are plotted regardless of the input values) when the user clicks on the "Update Chart" button. Where the graph is steep, there is a high cost penalty for a modest increase in protection level. Conversely, where the graph is flat there is a large gain in protection with each additional dollar. This scenario can be printed by clicking on the button "Print Scenario."

### 2. Repair Parts List

At any point that the user wishes to view the actual list of repair parts and quantities generated by the scenario and protection level, a hard copy can be printed by clicking on the "Print Report" button. The report for the Figure 3.2 scenario is provided in Table 3.2.

## E. THE INTERNAL FUNCTIONS OF THE SPREADSHEET

Once the user has selected the inputs that make up the scenario, the spreadsheet processes them internally through a series of mathematical steps. First, a cumulative Poisson distribution table, driven by the scenario, is generated for each repair part. Each repair part's annual BRF is adjusted for the user's inputs to arrive at a probability of failure during the "Lead Time" selected. The cumulative Poisson table is arrayed in columns from zero to ten. The heading for each column (zero to ten) reflects the number of repair parts required to achieve the protection levels in that column. The cumulative probabilities below the heading, of three for example, reflect the probability that there would be three or

| NIIN | Nomenclature | Unit Cost | Quantity | Total Cost | REPAIR PARTS SUMMARY | |
|---|---|---|---|---|---|---|
| M5340-01-298-3012 | CATCH, CLAMPING | $ 23.00 | 3 | $ 69.00 | | |
| M5310-01-297-5909 | GASKET, HOSE CONN | $ 4.80 | 3 | $ 14.40 | | |
| M4240-01-298-3005 | INLINE FILT ASSY | $ 254.00 | 3 | $ 762.00 | Leadtime = | 90 |
| M4730-01-296-5863 | CLAMP, HOSE NO 1 | $ 11.50 | 2 | $ 23.00 | OPTEMPO = | 1 |
| M4730-01-297-0908 | CLAMP, HOSE NO 2 | $ 11.50 | 2 | $ 23.00 | Protection = | 0.971 |
| M4720-01-297-5982 | HOSE, AIR BREATHING | $ 9.00 | 2 | $ 18.00 | # MK 16 (Active) = | 4 |
| H6685-01-297-0965 | OX HI PRESS GAGE ASSY | $ 1,430.00 | 2 | $ 2,860.00 | #MK 16 (Lay-up) = | 0 |
| M5305-01-296-5797 | SCREW, MACH, BLEED | $ 17.50 | 1 | $ 17.50 | | |
| M4820-01-298-3011 | VALVE CHECK | $ 10.50 | 1 | $ 10.50 | | |
| M5360-01-298-2994 | SPRING, HLCL, CPRSN | $ 6.90 | 1 | $ 6.90 | | |
| M5305-01-299-9746 | SCREW, SHOULDER | $ 11.00 | 1 | $ 11.00 | | |
| M4730-01-297-5960 | FITTING, FEMALE | $ 92.00 | 1 | $ 92.00 | | |
| M4730-01-297-5960 | FITTING, FEMALE | $ 92.00 | 1 | $ 92.00 | | |
| M5305-01-296-5799 | SCREW, MACH,PHD #6 | $ 3.70 | 1 | $ 3.70 | | |
| H5915-01-296-5892 | CENTER SECTION | $ 4,060.00 | 1 | $ 4,060.00 | | |
| H5935-01-295-9130 | CONN HSG ASSY ELEC | $ 2,480.00 | 1 | $ 2,480.00 | | |
| M4820-01-295-9266 | DIAPHRAM | $ 76.00 | 1 | $ 76.00 | | |
| M5340-01-297-0909 | CLAMP, LOOP ASSY | $ 19.00 | 1 | $ 19.00 | | |
| M5935-01-295-9129 | BATT CONT BRD ASSY | $ 37.00 | 1 | $ 37.00 | | |
| M5305-01-296-5800 | SCREW, MACH,PHD #6 | $ 3.70 | 1 | $ 3.70 | | |
| M5305-01-295-9121 | SCREW, MACH, PNH | $ 3.70 | 1 | $ 3.70 | | |
| M5340-01-296-5904 | VALVE, HANDWHEEL | $ 22.50 | 1 | $ 22.50 | | |
| H8120-01-297-0901 | DIL VALVE ASSY | $ 1,810.00 | 1 | $ 1,810.00 | | |
| M4710-01-300-9986 | TUBE ASSY, INL FIL-T | $ 298.00 | 1 | $ 298.00 | | |
| H5980-01-297-0920 | SECONDARY DISP ASSY | $ 4,060.00 | 1 | $ 4,060.00 | | |
| M5961-01-297-0949 | PRI DISPLAY ASSY | $ 495.00 | 1 | $ 495.00 | | |
| M4820-01-298-2826 | VALVE, CHECK ASSY | $ 1,234.00 | 1 | $ 1,234.00 | | |
| H4820-01-295-9157 | REG DIL ASSY | $ 2,040.00 | 1 | $ 2,040.00 | | |
| H4820-01-295-9158 | OXY REG MTD ASSY | $ 2,040.00 | 1 | $ 2,040.00 | | |
| H4820-01-295-9155 | DIL REG ASSY | $ 1,600.00 | 1 | $ 1,600.00 | | |
| H4820-01-295-9156 | OXY REG ASSY | $ 1,600.00 | 1 | $ 1,600.00 | | |
| H4820-01-299-9859 | BYPASS VALV ASSY DIL | $ 606.00 | 1 | $ 606.00 | | |
| M4820-01-296-5887 | BODY, VALVE SUBASSY | $ 49.00 | 1 | $ 49.00 | | |
| H4820-01-299-9860 | BYPASS VALV ASSY OXY | $ 736.00 | 1 | $ 736.00 | | |
| M5340-01-297-5955 | LID, CANISTER | $ 164.00 | 1 | $ 164.00 | | |
| M5305-01-296-5801 | SCREW, MACH | $ 3.70 | 1 | $ 3.70 | | |
| H5998-01-297-0946 | PRI ELECTRONIC DISP | $ 6,390.00 | 1 | $ 6,390.00 | | |
| M5305-01-296-5796 | SCREW, MACH,FH.82#6 | $ 3.70 | 1 | $ 3.70 | | |
| H4810-01-297-5976 | OXY ADDITION VALVE | $ 6,010.00 | 1 | $ 6,010.00 | | |
| H4820-01-297-5977 | OXY VALVE REG | $ 1,050.00 | 1 | $ 1,050.00 | | |
| M5340-01-296-5838 | WAIST STRAP ASSY RT | $ 396.00 | 1 | $ 396.00 | | |
| M5340-01-299-9780 | COVER ASSY | $ 375.00 | 1 | $ 375.00 | | |
| M5340-01-299-9781 | WAIST STRAP ASSY LEF | $ 369.00 | 1 | $ 369.00 | | |
| M5340-01-297-0986 | SHOULD STRAP LEFT | $ 111.00 | 1 | $ 111.00 | | |
| H5935-01-296-5829 | FLTG, BHD, ASSY, ELEC | $ 706.00 | 1 | $ 706.00 | | |
| M4710-01-297-0924 | TUBE ASSY | $ 497.00 | 1 | $ 497.00 | | |
| M4710-01-297-0995 | TUBE ASSY, DIL REG | $ 478.00 | 1 | $ 478.00 | | |
| M4710-01-297-0994 | TUBE ASSY, FL CTRL, OX | $ 397.00 | 1 | $ 397.00 | | |
| M4710-01-297-0997 | TUBE ASSY, DIL BP SC | $ 396.00 | 1 | $ 396.00 | | |
| M4710-01-297-0991 | TUBE ASSY, DIL REG TO | $ 350.00 | 1 | $ 350.00 | | |
| M4710-01-297-0998 | TUBE ASSY, DIL S T T S | $ 350.00 | 1 | $ 350.00 | | |
| M4710-01-297-0999 | TUBE ASSY, DIL S T TO | $ 342.00 | 1 | $ 342.00 | | |
| M4710-01-297-0992 | TUBE ASSY DIL S TEE D | $ 315.00 | 1 | $ 315.00 | | |
| M4710-01-297-0993 | TUBE ASSY OX S T OX | $ 174.00 | 1 | $ 174.00 | | |
| M5310-01-297-0889 | NUT, ACORN | $ 5.80 | 1 | $ 5.80 | | |
| M1386-01-304-7142 | MOUTHPIECE | $ 1,560.00 | 1 | $ 1,560.00 | | |
| M5325-01-297-0899 | GROMMET, NONMETALLI | $ 11.00 | 1 | $ 11.00 | | |
| | | | | | | |
| | | TOTAL COST = | | $ 47,727.10 | | |
| | | | | | | |

Table 3.2 Repair Parts Summary Report Generated For Scenario Described in Figure 2.3.

less parts demanded. Under the heading four, are the probabilities for each repair part that there would be four or less repair parts demanded, and so on up to ten or less repair parts demanded. Figure 3.3 shows an example of the cumulative values generated for the first few repair parts for the Figure 3.2 scenario. The cumulative table could be designed for any number of failures but was limited to ten failures maximum to remain within the practical scope of this paper. Equation 3.1, used to generate the cumulative Poisson table, is an inverse variation of Equation 1.1.

$$P(X \le n) = \sum_{x=1}^{n} \frac{e^{-\mu}\,\mu^{x}}{x!} \qquad (3.1)$$

| ***Selected Repair Parts*** | | | | **Number of Repair Parts Required** | | | |
|---|---|---|---|---|---|---|---|
| **Item Rank** | | Prob of Instock | | | | | |
| **by Demand** | **Item Name** | **0** | **1** | **2** | **3** | **4** | **5** |
| 1 | CATCH, CLAMPING | 0.337925 | 0.704550 | 0.903432 | 0.975356 | 0.994865 | 0.999098 |
| 2 | GASKET, HOSE CONN | 0.365669 | 0.733542 | 0.918587 | 0.980640 | 0.996247 | 0.999387 |
| 3 | INLINE FILT ASSY | 0.477245 | 0.830275 | 0.960848 | 0.993044 | 0.998998 | 0.999879 |
| 4 | CLAMP, HOSE NO 1 | 0.641571 | 0.926323 | 0.989514 | 0.998863 | 0.999901 | 0.999993 |
| 5 | CLAMP, HOSE NO 2 | 0.641571 | 0.926323 | 0.989514 | 0.998863 | 0.999901 | 0.999993 |
| 6 | HOSE, AIR BREATHING | 0.743869 | 0.963973 | 0.996536 | 0.999748 | 0.999985 | 0.999999 |
| 7 | OX HI PRESS GAGE ASSY | 0.762439 | 0.969237 | 0.997283 | 0.999818 | 0.999990 | 1.000000 |
| 8 | SCREW, MACH, BLEED | 0.789218 | 0.976036 | 0.998147 | 0.999892 | 0.999995 | 1.000000 |
| 9 | VALVE CHECK | 0.800981 | 0.978733 | 0.998456 | 0.999915 | 0.999996 | 1.000000 |
| 10 | SPRING, HLCL, CPRSN | 0.827480 | 0.984180 | 0.999017 | 0.999954 | 0.999998 | 1.000000 |

**Figure 3.3 Sample of Cumulative Poisson Table Generated For Scenario in Figure 3.2.**

The next significant step incorporates the "LOOKUP" function of the EXCEL 5.0 program. Using the "Minimum Protection Level" input by the user, the LOOKUP function, with an inverse function, reviews each repair part's array of probabilities for the closest value present that is not less

than the protection level inputted. The value at the top of that column of probabilities is the quantity of repair parts required to achieve that protection level. This quantity is multiplied by the unit cost and summed with the other repair parts costs to provide the "Inventory Cost of the Protection Level." An example of the LOOKUP function is:

```
= LOOKUP(MPL,AA2:AK2,AA1:AK1)
```

where MPL is the Minimum Protection Level cell entered on the Control Panel. AA2:AK2 is the range of cells holding that repair part's cumulative Poisson array and AA1:AK1 is the array of the cumulative Poisson table's column headings.

The graph provided on the control panel is driven by a macro command written in EXCEL's VISUAL BASIC language. A column of twenty protection levels, from 0.895 to 0.995 with an increment of 0.005, is listed on the page below the Control Panel. The macro command is activated when the "Update Chart" button is clicked. When activated, the macro takes the first value in the protection level column and types the value to the cell "Minimum Protection Level" and then enters to refresh the data. The "Minimum Protection Level" cell is continuously linked to the rest of the spreadsheet and so immediately updates the dependent cells. The macro then reads the dependent cell "Total Cost" and types it to the cell next to the protection level cell used. The macro loops until all the protection levels have been entered into the calculation and the resultant "Total Costs" have been recorded in the column adjacent to the column of protection levels. These two columns are linked to the graph on the Control Panel which updates as each entry in the column changes.

Two other macros control the process of printing from the Control Panel. The button "Print Report" prints the basic information required to identify the repair parts required to

achieve the protection level in the selected scenario (See Table 3.2). The button "Print Scenario" prints the range of cells that comprise the control panel in Figure 3.2.

## F. LIMITATIONS OF SOFTWARE AND HARDWARE

This spreadsheet is written in EXCEL version 5.0 in the WINDOWS version 3.1 environment. Translating to other spreadsheet formats has not been attempted. We expect all data and virtually all the formulas to be converted to most spreadsheets, for example LOTUS 1-2-3 version 5.0. However, there may be a problem in translating the macros. The model was run using an IBM compatible 486/33 MHz with 8 meg of RAM. Systems with less RAM may crash or run slower during the "Chart Update" function.

The scope of this thesis deliberately focuses the attention on the few parts that were expected to be the most burden on the budget. With only 78 repair parts included, the inventory manager is left to use other means to calculate the quantities for the other parts.

The cumulative Poisson table incorporated in this spreadsheet is limited to a maximum of ten or less repair parts demanded. Scenarios that require more than ten parts will generate a failure signal. Large populations of MK 16, long lead time, high OPTEMPO, or a combination of these variables, will result in a #N/A symbol in the "Total Cost" cell. Generally, the spreadsheet's target was to support an EOD Det with four to six MK 16, lead times of less than 90-days, and OPTEMPO less than ten times the SPCC reflected OPTEMPO. Within these boundaries the failure signal is still likely but it can be manipulated out by progressively easing the constraints to a scenario not significantly different from was intended.

In Chapter IV, three scenarios will be presented with a comparison of the outcomes from this spreadsheet and the SPCC COSAL/APL program.

## IV. INVENTORY METHODS COMPARISON AND EVALUATION

### A. METHODOLOGY

In Chapter III, we presented the methodology of both the APL model and the proposed spreadsheet model for the selection of inventories to support the MK 16 when deployed from the parent command. In this chapter, we will explore three cases that compare the two models. Our basis for comparison will be the average protection level for the modeled inventory, the minimum protection level within the range of repair parts, and the total cost of the inventory.

The average protection level provides a general feeling for how robust the inventory is overall. The minimum protection level within an inventory identifies potential stockout candidates. For example, an inventory manager may achieve an overall average protection of 0.995 but may have several items with little or no protection. These few low protection items do not lower the average significantly but will still cause stockout problems.

The costs of the inventories provide the third factor of our bottom line. Protection levels should include the associated costs to gauge the overall effect on the command's budget; an extremely high and expensive protection level for the MK 16 is of little value if the other equipment supporting the mission were underfunded.

With our comparators established, our evaluation of the inventories must be balanced. The APL model provides a different inventory dependent on the number of MK 16 assigned. Listed in columns for (4), (5-8), and (9-20) systems, the three different inventories identify the types and quantities of repair parts authorized (See Table 3.1). These are preset quantities with the assumptions of a 90-day lead time, OPTEMPO based on the average of the last ten months, and a goal of 0.90 protection or better. Also preset is the cost of each

inventory; only with reevaluation by SPCC will these presets change.

To identify the protection level achieved for an APL repair part we use the quantity allowed for that part and enter the associated column within the cumulative Poisson table. The value listed for that part in the cumulative Poisson table is the probability of less than or equal to that number of repair parts being demanded. This is the protection level for that repair part. The average of the protection levels of all the repair parts and the minimum protection level found within the list of repair parts are the comparators of that APL column. If the scenario is changed, the cumulative Poisson table will change to reflect a different demand distribution. This will generate a different average and minimum protection level for that column's inventory.

The proposed spreadsheet model is able to adjust the type and quantity of repair parts as each input to the scenario changes. Either the average protection level or inventory cost can be held constant as the scenario changes. This allows us to explore two options, that of finding the least costly inventory that provides as much protection as the APL, or finding the highest protection level possible without exceeding the current costs of the APL. For our comparisons, the variable held constant will be adjusted to be as close to the APL's value as possible. If the spreadsheet model's cost is to be held constant with that of the APL, the model's cost will be adjusted to be equal to or less than the APL cost. If average protection level is to be held constant with the APL, the spreadsheet model's protection level will be adjusted to be equal to, or greater than the APL's value.

In the case that follows, we will monitor the overall average protection levels, minimum protection level, and the costs for various scenarios. Figure 4.1 provides a brief

| | Case One: Lead Time = 90 Days, OPTEMPO Changes from 1 to 5, Number of Active MK 16 = 4 Costs Approx. Equal | | Case Two (a): Lead Time Changes from 15 to 90 Days, OPTEMPO = 1, Number of Active MK 16 = 4 Costs Approx. Equal | |
|---|---|---|---|---|
| | APL (4) Model | Spreadsheet Model | APL (4) Model | Spreadsheet Model |
| Highest Average P. L. Achieved | 0.989 | 0.994 | 0.999 | 0.999 |
| Lowest Average P. L. Achieved | 0.884 | 0.935 | 0.989 | 0.994 |
| Highest Minimum P. L. Achieved | 0.903 | 0.973 | 0.996 | 0.997 |
| Lowest Minimum P. L. Achieved | 0.093 | 0.841 | 0.903 | 0.976 |
| Cost | $46,131 | $43,142 to $46,848 | $46,131 | $44,726 to $46,032 |

| | Case Two (b): Lead Time Changes from 15 to 90 Days, OPTEMPO = 1, Number of Active MK 16 = 4 Avg Protection Levels Approx. Equal | | Case Three (a): Desert Storm with Lead Time = 45 Days, OPTEMPO = 5, Number of Active MK 16 = 4 Costs Approx. Equal | |
|---|---|---|---|---|
| | APL (4) Model | Spreadsheet Model | APL (4) Model | Spreadsheet Model |
| Highest Average P. L. Achieved | 0.999 | 0.999 | 0.950 | 0.972 |
| Lowest Average P. L. Achieved | 0.989 | 0.989 | N/A | N/A |
| Highest Minimum P. L. Achieved | 0.996 | 0.996 | 0.490 | 0.917 |
| Lowest Minimum P. L. Achieved | 0.903 | 0.966 | N/A | N/A |
| Cost | $46,131 | $40,706 to $44,412 | $46,131 | $42,506 |

| | Case Three (b): Desert Storm with Lead Time = 45 Days, OPTEMPO = 5, Number of Active MK 16 = 4 Proposed Min Protection Level > 0.90 | | Case Three (c): Desert Storm with Lead Time = 45 Days, OPTEMPO = 5, Number of Active MK 16 = 4 Proposed Average Protection Level > 0.95 | |
|---|---|---|---|---|
| | APL (4) Model | Spreadsheet Model | APL (4) Model | Spreadsheet Model |
| Highest Average P. L. Achieved | 0.950 | 0.962 | 0.950 | 0.956 |
| Lowest Average P. L. Achieved | N/A | N/A | N/A | N/A |
| Highest Minimum P. L. Achieved | 0.490 | 0.906 | 0.490 | 0.884 |
| Lowest Minimum P. L. Achieved | N/A | N/A | N/A | N/A |
| Cost | $46,131 | $27,763 | $46,131 | $26,539 |

Figure 4.1 Scenario Descriptions with Outcomes.

summary of each case with the results for quick comparison. Greater detail for evaluating an individual scenario is provided with the graphs associated with each case.

## B. CASE 1: THE EFFECT OF INCREASES IN OPTEMPO ON MINIMUM AND AVERAGE PROTECTION LEVELS

The first case begins with the original APL assumptions of lead time = 90 days, active MK 16 = 4, and OPTEMPO = 1. An increase in OPTEMPO is reflected as an increase in the demand rate for repair parts (These parameters are discussed in greater detail in Chapter III). If an EOD Det has doubled its OPTEMPO, then its consumption of repair parts will be expected to double. During Desert Storm, one EOD Det dove over 90-days in a four month period; a substantial increase over normal operations of 15 to 25 training dives in the same period.

Figure 4.2 displays the relationship between the two models' minimum and average protection levels and OPTEMPO as OPTEMPO increases. The APL (4) column enjoys a large number of repair parts included as insurance items. As discussed in Chapter II and displayed in Figure 2.3, insurance items have a higher average protection level than demand items. With OPTEMPO set at one, the APL (4) column provides most of the repair parts at a protection level of 0.995 or higher. This brings the average protection level up to 0.989. A gap exists as the BRF for a repair part increases to the level of it becoming a demand item rather than an insurance item. Again as displayed in Figure 2.3, demand items are stocked at protection levels that range from 0.995 to 0.900. In fact, the APL (4) has one repair part with a protection level of 0.903. This range is still acceptable within the SPCC goal of 0.900 or greater protection.

The proposed spreadsheet inventory model provides only a slightly higher average protection level at an OPTEMPO of one, 0.994 vs. 0.989 for the APL model. However, the minimum

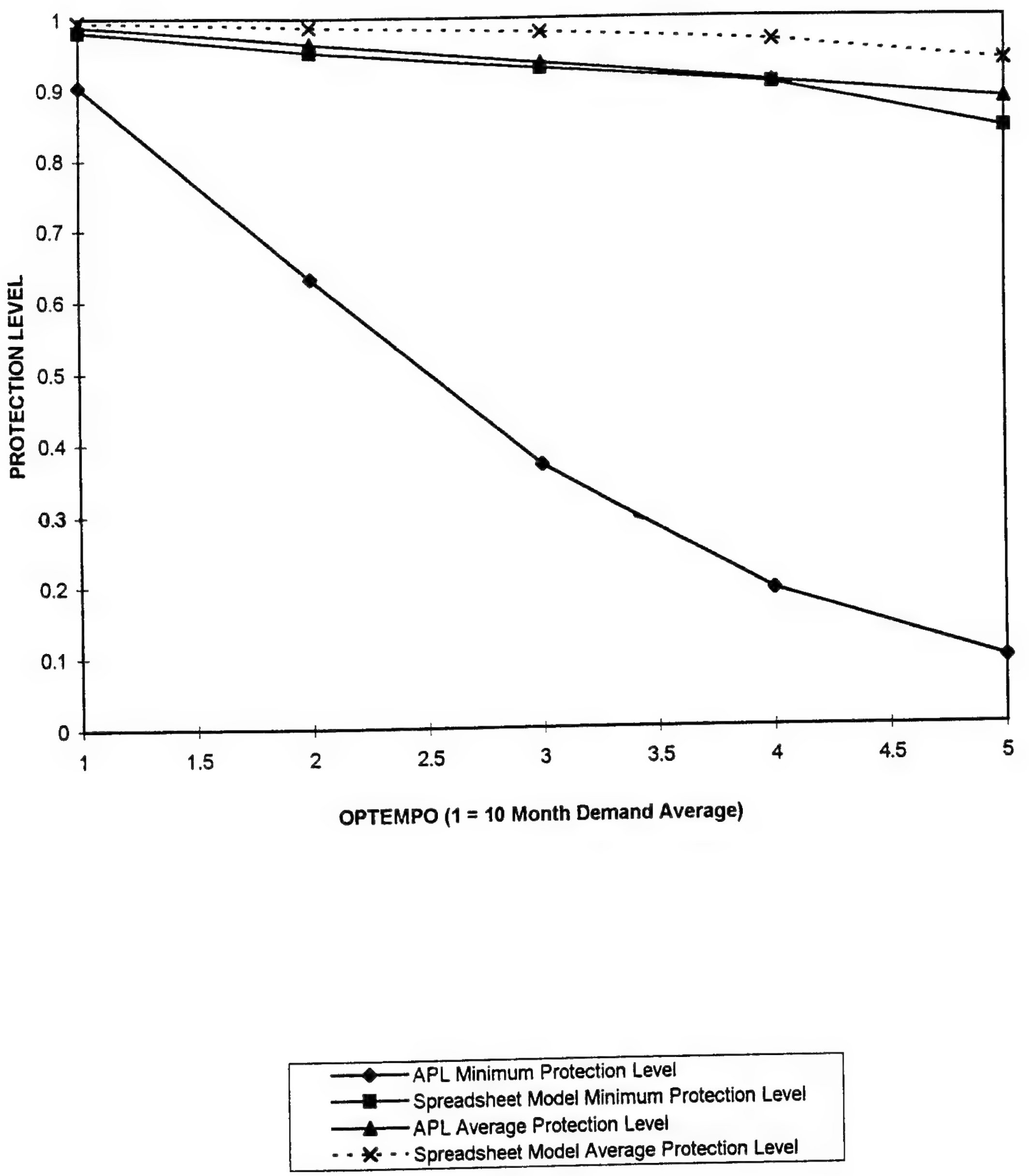


Figure 4.2 Comparison of Protection Levels for the APL (4) Column and the Spreadsheet Model as OPTEMPO Increases (Spreadsheet Model Costs ≤ APL Costs).

protection levels at this OPTEMPO are significantly different; APL (4) inventory minimum of 0.903 vs. 0.973 minimum protection for the spreadsheet model (These values are displayed in tabular form in Figure 4.1). The spreadsheet has the flexibility to adjust the stock level on items that have an inherent protection level that is acceptable to the user. The money saved on these items is then applied to items with protection levels that are lower than acceptable. The costs are held constant and the average protection level is similar, but the deviation from the average is reduced. By *increasing* the probability of a stockout on some insurance items by as little as 0.005, we were able to *decrease* the probability of a stockout on high usage demand items as much as 0.090.

As OPTEMPO increases, the APL (4) average protection level drops at nearly the same rate as for the spreadsheet. At an OPTEMPO five times greater than normal, the APL (4) average is 0.884 while the spreadsheet average is 0.935. The minimum protection level for the APL (4) falls at a much faster rate. As the demand rate increases for those items without insurance protection, their probability of experiencing a stockout grows. Although an insurance item with a 0.996 protection level at an OPTEMPO of one drops only to 0.919, the demand item with a protection level of 0.903 drops to 0.093 (See Figure 4.1).

The ability of the spreadsheet to adjust the repair parts quantities results in all repair parts stocked at a minimum protection level over 0.841 for the same cost as the APL (4). In fact, the model that provided the spreadsheet protection levels described here required a much lower cost than the APL (4) so that we could meet our criterion of not exceeding the cost of the APL (4) inventory. Where the APL (4) cost $46,131, the spreadsheet model cost $ 43,142; a savings of nearly $ 3,000. Project this savings, to include all the

costs of inventory, over the fleet and the gain is substantial for both budgets and operations.

## C. CASE 2: THE EFFECT OF CHANGES IN LEAD TIMES ON MINIMUM AND AVERAGE PROTECTION LEVELS

The second case focuses on the effect of lead times. Using the inputs of four active MK 16, OPTEMPO of one and costs held constant, we see a decline in protection levels as lead time increases. (Figure 4.3) With a short lead time of 15 days and 30 days, both the APL (4) column and the spreadsheet have very similar average and minimum protection levels above 0.990. As lead time increases, the APL (4) minimum protection level drops to the minimum acceptable level, near 0.900.

The relationship of increased protection as the lead times shorten reflects a decreased pressure on the inventory stock between restocks. If two parts in inventory provide a 0.900 protection level during a 90-day demand period, there is a 90% probability that two, or less, parts will be demanded. If the demand period is shortened, the probability that the demand will be two or less during that period will increase. Stated another way, as lead times get shorter, there is less need for inventory. An EOD Det with access to overnight delivery service could operate with virtually no inventory. On a cautionary note, lead times can vary widely from order to order and the worst possible case should be the estimate.

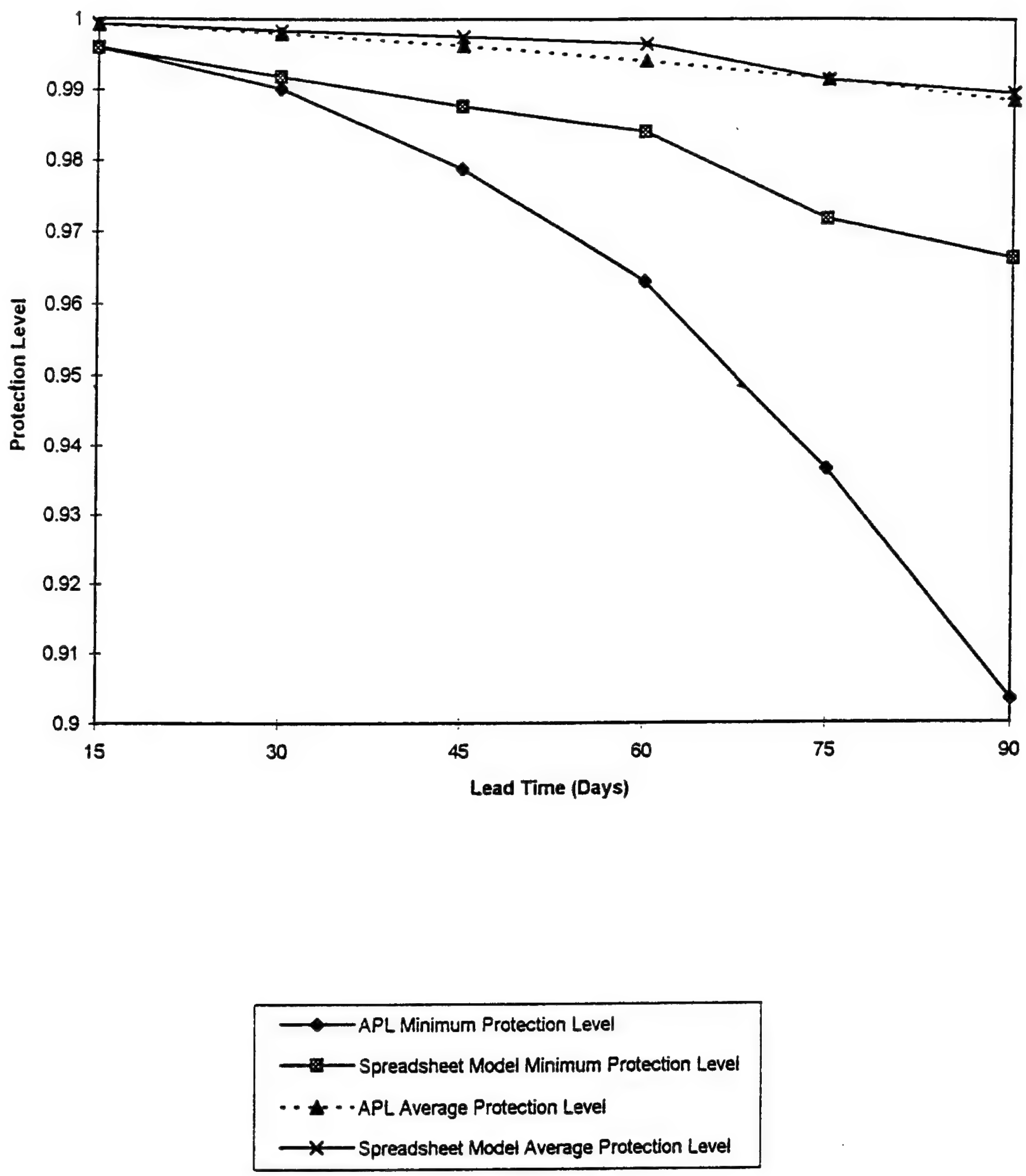


Figure 4.3 Comparison of Protection Levels for APL (4) Inventory and Spreadsheet Model Inventory as Lead Time Changes From 15 to 90 Days.

As lead time decreases, the inventory manager has the choice of reducing the inventory quantities to maintain the historical protection levels and reap the cost savings, or maintain the inventory levels and costs to enjoy a much higher than historical protection level. Figure 4.3 displays the route of holding costs constant as lead time decreases. The APL (4) column's fixed inventory list and costs only permit us to gain the benefits of increased protection at the historical cost. The spreadsheet approach allows us to identify what the cost savings would be if we hold protection levels at their historical values. Figure 4.4 displays the inventory cost/lead time relationship with the average protection level held constant at the APL (4) level with 90-day lead time. If a conservative inventory manager believed that lead time was truly 90 days, the spreadsheet generated inventory would cost $40,706 with an average protection level of 0.990 and a minimum protection level of 0.966. (See Figure 4.2) Compared to the APL (4) column cost of $46,131, average protection level of 0.989 and minimum protection level of 0.903, the spreadsheet provides a savings of $5,425 and an increase in the minimum protection level from 0.903 to 0.966.

If the inventory manager is convinced that the lead time is shorter, the savings increase with every reduction until, at around a 15 day lead time, the spreadsheet model inventory cost becomes zero. The inherent reliability of the MK 16 individual parts provide a minimum probability 0.966 and an average probability of 0.989 that no parts will be required during that 15 day period. This assumes the OPTEMPO of one and that there is no reason to take advantage of any increased protection levels.

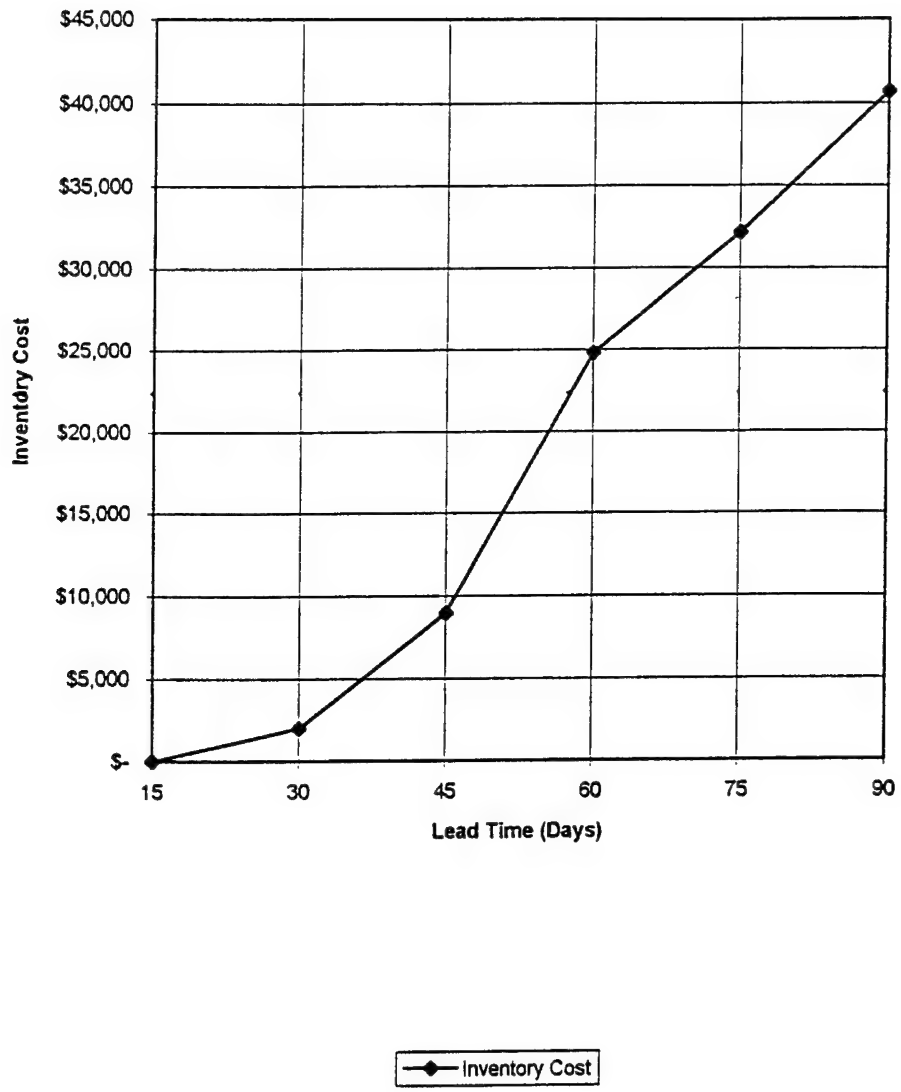


Figure 4.4 Spreadsheet Model Inventory Cost Changes as Lead Time Changes from 15 to 90 Days (Spreadsheet Model Average Protection Level ≥ APL (4) Average Protection Level of 0.9885).

## D. CASE 3: DESERT STORM

### 1. Worst Case Scenario

Forecasting the demands that an inventory will experience is the most difficult task. Forecasting based on past demands, like the last ten quarters average demand, results in an inventory very capable of supporting an average quarter at a reasonable cost. Forecasting for the worst possible case provides an inventory that in an average quarter appears so robust as to be wasteful, yet is the minimum required to support the worst case scenario. Case 3 describes a model experienced by some EOD Dets during and immediately following Desert Storm in 1991. The factors used in this case were compiled from telephone interviews with people both on the supply and the receiving ends of the repair parts pipeline. This is not meant to document Desert Storm, but to provide an approximation of the episode as an example of worst case demand.

### 2. OPTEMPO

Once established, the EOD Det began MCM operations that stabilized at a six-day-on, one-day-off schedule. Some operations exceeded ten days straight of diving. Each of the four MK 16 were readied for each diving day. Out of a deployment of 120 days, the EOD Det conducted diving operations approximately 90 to 100 days.

Peace-time OPTEMPO used by SPCC is an average of the demand over the last ten quarters. Some EOD personnel estimate their normal schedule provides an average of one to two diving days a week for training. For the purposes of this case, we will estimate that Desert Storm OPTEMPO was five times greater than the normal.

### 3. Lead Time

Once a repair parts pipeline has been established, resupply becomes more routine and predictable. Initially, the EOD Det went nearly 30 days before the first order arrived. After that, a normal reorder would be filled in an average of 14 days, and a special order would be filled in ten days. Orders would be transmitted electronically to the parent command and processed within 24 hours, then immediately shipped. The order would arrive in the geographic area of the EOD Det in three to five days. Transporting the order from the geographic depot to the EOD Det embarked at sea could take an additional week.

As conservative inventory managers, we will use 45 days as the lead time estimate. This covers the actual 30 day maximum lead time experienced and a buffer of an additional 15 days.

### 4. Protection Level, Cost, and Rational Analysis

At this point the inventory manager has arrived at the estimates for OPTEMPO and lead time with the number of active MK 16 fixed at four. As discussed in the first two cases, the inventory manager can choose to maximize protection level within a prescribed budget or to prescribe an acceptable protection level and obtain the minimum cost. A third method would be to analyze the graph provided on the control panel to determine if there is a point that permits a large increase in protection level for only a small increase in cost. Using a budget figure that is just short of a huge increase in protection might be a false economy.

For the purposes of comparing the APL (4) inventory to the spreadsheet model's inventory we will run four scenarios. The first will assume that the inventory manager wants the highest possible protection level available without exceeding the APL (4) cost. In the second scenario, the inventory manager wants to minimize costs and while maintaining the

protection levels intended for the APL (4); no item with a protection level less than 0.900. Additionally, the average protection level achieved for the APL (4) inventory will be tested. The fourth scenario will be a rational analysis of the spreadsheet's Control Panel graph. The assumption will be that the inventory manager has some leeway with picking the amount budgeted for this mission and will search for a point on the graph that achieves a high marginal return for the cost.

#### a. *What is the Maximum Average Protection Level that can be Achieved Within the Cost Constraint of the APL (4) Inventory?*

The process begins by entering the Control Panel of the spreadsheet with a lead time of 45 days, OPTEMPO of 5, and 4 active MK 16. Clicking the button marked "Update Chart" refreshes the chart based on the new inputs. The macro command attached to the button will cycle through the possible minimum protection levels from 0.900 to 0.995, stopping at 0.995 and generating the "Total Cost" of the inventory that achieves that the protection level of 0.995.

With your budget defined as the cost of the APL (4) column, $46,131, systematically reduce the entry in "Enter Minimum Protection Level" until the "Total Cost" output is $46,131 or less. Following this process we obtain an inventory cost of $42,506; a $3,625 savings. Average protection level is 0.972 and the minimum protection level for any repair part is 0.917. (See Figure 4.2) The cost savings in this case was unavoidable given the constraint of not exceeding the cost of APL (4). If permitted a slight overrun of less that 1% ($404), we can reduce the average chance of a stockout by 44% (2.76% to 1.57%). This also increases the average protection level from 0.972 to 0.984 and the minimum protection level from 0.917 to 0.940. This compares well to

the protection levels generated by the APL (4) inventory. If the APL (4) inventory was used, the average chance of a stockout more than triples (1.57% to 4.97%). More important, the minimum protection level has dropped to 0.490 with nine high demand items having a protection level less than the minimum acceptable level of 0.900.

### *b. What is the Cost Saving if a Minimum Protection Level of 0.900 is Selected?*

Without changing the other inputs listed above, change the "Minimum Protection Level" entry to 0.900. The average protection level is still higher than provided by APL (4), 0.962, and it is achieved at a total cost of $27,763. This $18,368 savings has the advantages of a higher minimum and average protection level than the APL (4) achieves with an inventory that anticipates a wartime preparedness.

### *c. What is the Cost Savings if the Spreadsheet Model's Average Protection Level is Set Equal to that Achieved by the APL (4) Inventory?*

The APL (4) inventory achieved an average protection level of 0.950 and a minimum protection level of 0.490. The procedure for comparing the average and minimum protection levels requires entering the spreadsheet beyond the Control Panel. A hidden area to the right of the Control Panel generates the average and minimum protection levels. To analyze the question posed, the "Enter Minimum Protection Level" input would be systematically adjusted until the spreadsheet's average protection level was approximately equal to the APL (4)'s average protection level of 0.9503. The total cost for the spreadsheet model's inventory is $26,539 with an average protection level of 0.956 and a minimum protection level of 0.884.

### d. *At What Points on the Control Panel Graph is there the Greatest Marginal Gain in Protection at an Acceptable Cost?*

Figure 4.5 provides the printout of the Control Panel view for Case 3. To find points on the graph that might yield the greatest gain in protection for the dollar, systematically adjust the "Enter Minimum Protection Level" input around the points on the graph at the beginning of a steep section. The horizontal areas show a section where a small vertical rise in costs generates a large horizontal jump in protection. The point at the right-hand end of one of these large horizontal jumps is where any additional increase in protection incurs a large cost penalty. This might be the addition of a few high cost repair parts needed to achieve the next higher level of protection.

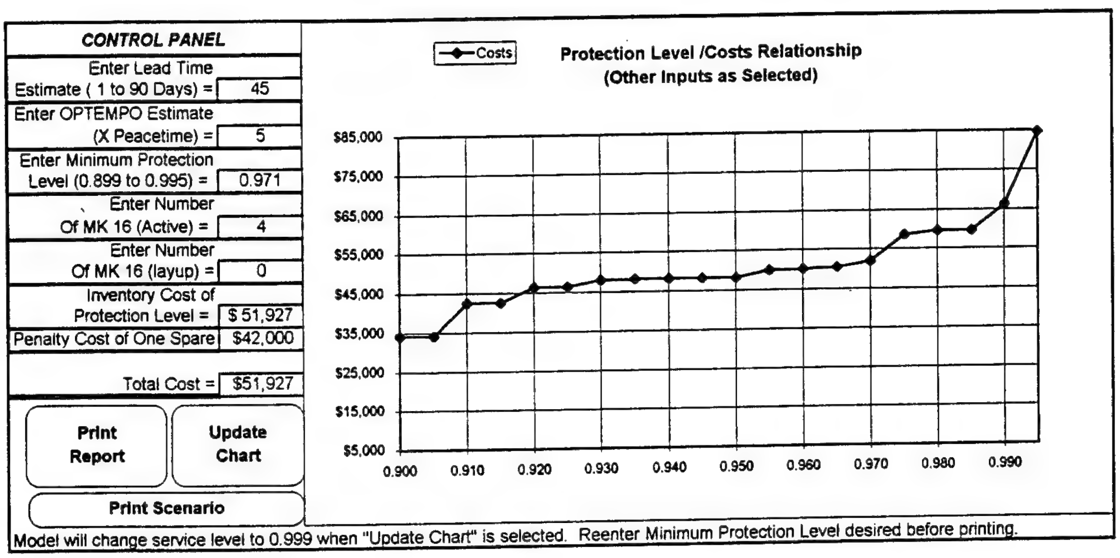


**Figure 4.5. View of Control Panel for Case 3 Rational Analysis.**

All inventory managers are constrained by some budget limit, but there is usually some latitude. Looking at

the graph in Figure 4.5, one point worth investigating at the low cost/low protection level end of the graph would be in the vicinity of 0.905. A cost increase of nearly $10,000 is required to obtain the next small increase in protection. Once the plateau of $46,535 is reached, the minimum protection level can be increased from 0.918 to 0.971 for only an 11.6% increase in costs. This additional $5,392 reduces the average chance of a stockout 55%, from 1.57% to 0.70%. The proposed inventory generated by the spreadsheet for this scenario is provided as Table 4.1. If this is deemed a critical mission, a third point, 0.986, would cost nearly $60,000. Advances in protection level beyond this point are exceedingly costly. If greater protection is important, a more practical direction might be to use a portion of the funds to further reduce the lead time.

Table 4.1 Repair Parts Summary Report Generated For Scenario Described in Figure 4.5.

| NIIN | Nomenclature | Unit Cost | Quantity | Total Cost |
|---|---|---|---|---|
| M5340-01-298-3012 | CATCH, CLAMPING | $ 23.00 | 6 | $ 138.00 |
| M5310-01-297-5909 | GASKET, HOSE CONN | $ 4.80 | 6 | $ 28.80 |
| M4240-01-298-3005 | INLINE FILT ASSY | $ 254.00 | 5 | $ 1,270.00 |
| M4730-01-296-5863 | CLAMP, HOSE NO 1 | $ 11.50 | 3 | $ 34.50 |
| M4730-01-297-0908 | CLAMP, HOSE NO 2 | $ 11.50 | 3 | $ 34.50 |
| M4720-01-297-5982 | HOSE, AIR BREATHING | $ 9.00 | 3 | $ 27.00 |
| H6685-01-297-0965 | OX HI PRESS GAGE ASSY | $ 1,430.00 | 3 | $ 4,290.00 |
| M5305-01-296-5797 | SCREW, MACH, BLEED | $ 17.50 | 2 | $ 35.00 |
| M4820-01-298-3011 | VALVE CHECK | $ 10.50 | 2 | $ 21.00 |
| M5360-01-298-2994 | SPRING, HLCL, CPRSN | $ 6.90 | 2 | $ 13.80 |
| M5305-01-299-9746 | SCREW, SHOULDER | $ 11.00 | 2 | $ 22.00 |
| M4730-01-297-5960 | FITTING, FEMALE | $ 92.00 | 2 | $ 184.00 |
| ~~M4730-01-297-5960~~ | ~~FITTING, FEMALE~~ | ~~$ 92.00~~ | ~~2~~ | $ 184.00 |
| M5305-01-296-5799 | SCREW, MACH,PHD #6 | $ 3.70 | 1 | $ 3.70 |
| H5915-01-296-5892 | CENTER SECTION | $ 4,060.00 | 1 | $ 4,060.00 |
| H5935-01-295-9130 | CONN HSG ASSY ELEC | $ 2,480.00 | 1 | $ 2,480.00 |
| M4820-01-295-9266 | DIAPHRAM | $ 76.00 | 1 | $ 76.00 |
| M5340-01-297-0909 | CLAMP, LOOP ASSY | $ 19.00 | 1 | $ 19.00 |
| M5935-01-295-9129 | BATT CONT BRD ASSY | $ 37.00 | 1 | $ 37.00 |
| M5305-01-296-5800 | SCREW, MACH,PHD #6 | $ 3.70 | 1 | $ 3.70 |
| M5305-01-295-9121 | SCREW, MACH, PNH | $ 3.70 | 1 | $ 3.70 |
| M5340-01-296-5904 | VALVE, HANDWHEEL | $ 22.50 | 1 | $ 22.50 |
| H8120-01-297-0901 | DIL VALVE ASSY | $ 1,810.00 | 1 | $ 1,810.00 |
| M4710-01-300-9986 | TUBE ASSY, INL FIL-T | $ 298.00 | 1 | $ 298.00 |
| H5980-01-297-0920 | SECONDARY DISP ASSY | $ 4,060.00 | 1 | $ 4,060.00 |
| M5961-01-297-0949 | PRI DISPLAY ASSY | $ 495.00 | 1 | $ 495.00 |
| M4820-01-298-2826 | VALVE, CHECK ASSY | $ 1,234.00 | 1 | $ 1,234.00 |
| H4820-01-295-9157 | REG DIL ASSY | $ 2,040.00 | 1 | $ 2,040.00 |
| H4820-01-295-9158 | OXY REG MTD ASSY | $ 2,040.00 | 1 | $ 2,040.00 |
| H4820-01-295-9155 | DIL REG ASSY | $ 1,600.00 | 1 | $ 1,600.00 |
| H4820-01-295-9156 | OXY REG ASSY | $ 1,600.00 | 1 | $ 1,600.00 |
| H4820-01-299-9859 | BYPASS VALV ASSY DIL | $ 606.00 | 1 | $ 606.00 |
| M4820-01-296-5887 | BODY, VALVE SUBASSY | $ 49.00 | 1 | $ 49.00 |
| H4820-01-299-9860 | BYPASS VALV ASSY OXY | $ 736.00 | 1 | $ 736.00 |
| M5340-01-297-5955 | LID, CANISTER | $ 164.00 | 1 | $ 164.00 |
| M5305-01-296-5801 | SCREW, MACH | $ 3.70 | 1 | $ 3.70 |
| H5998-01-297-0946 | PRI ELECTRONIC DISP | $ 6,390.00 | 1 | $ 6,390.00 |
| M5305-01-296-5796 | SCREW, MACH,FH.82#6 | $ 3.70 | 1 | $ 3.70 |
| H4810-01-297-5976 | OXY ADDITION VALVE | $ 6,010.00 | 1 | $ 6,010.00 |
| H4820-01-297-5977 | OXY VALVE REG | $ 1,050.00 | 1 | $ 1,050.00 |
| M5340-01-296-5838 | WAIST STRAP ASSY RT | $ 396.00 | 1 | $ 396.00 |
| M5340-01-299-9780 | COVER ASSY | $ 375.00 | 1 | $ 375.00 |
| M5340-01-299-9781 | WAIST STRAP ASSY LEF | $ 369.00 | 1 | $ 369.00 |
| M5340-01-297-0986 | SHOULD STRAP LEFT | $ 111.00 | 1 | $ 111.00 |
| H5935-01-296-5829 | FLTG, BHD, ASSY, ELEC | $ 706.00 | 1 | $ 706.00 |
| M4710-01-297-0924 | TUBE ASSY | $ 497.00 | 1 | $ 497.00 |
| M4710-01-297-0995 | TUBE ASSY, DIL REG | $ 478.00 | 1 | $ 478.00 |
| M4710-01-297-0994 | TUBE ASSY, FL CTRL, OX | $ 397.00 | 1 | $ 397.00 |
| M4710-01-297-0997 | TUBE ASSY, DIL BP SC | $ 396.00 | 1 | $ 396.00 |
| M4710-01-297-0991 | TUBE ASSY, DIL REG TO | $ 350.00 | 1 | $ 350.00 |
| M4710-01-297-0998 | TUBE ASSY, DIL S T T S | $ 350.00 | 1 | $ 350.00 |

| *REPAIR PARTS SUMMARY* | |
|---|---|
| Leadtime = | 45 |
| OPTEMPO = | 5 |
| Protection = | 0.971 |
| # MK 16 (Active) = | 4 |
| #MK 16 (Lay-up) = | 0 |

Table 4.1 (Continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| M4710-01-297-0999 | TUBE ASSY, DIL S T TO | $ 342.00 | 1 | $ 342.00 | | |
| M4710-01-297-0992 | TUBE ASSY DIL S TEE D | $ 315.00 | 1 | $ 315.00 | | |
| M4710-01-297-0993 | TUBE ASSY OX S T OX | $ 174.00 | 1 | $ 174.00 | | |
| M5310-01-297-0889 | NUT, ACORN | $ 5.80 | 1 | $ 5.80 | | |
| M1386-01-304-7142 | MOUTHPIECE | $ 1,560.00 | 1 | $ 1,560.00 | | |
| M5325-01-297-0899 | GROMMET, NONMETALLI | $ 11.00 | 1 | $ 11.00 | | |
| M4710-01-296-5981 | TUBE ASSY, DIL ADD | $ 148.00 | 1 | $ 148.00 | | |
| M5305-01-296-5812 | NUT, JAM SMALL PATTER | $ 5.80 | 1 | $ 5.80 | | |
| M6150-01-297-0903 | CABLE ASSY, PRIMARY | $ 722.00 | 1 | $ 722.00 | | |
| M4240-01-297-5994 | CANISTER ASSY | $ 709.00 | 1 | $ 709.00 | | |
| M4820-01-297-5968 | SEAT, VALVE | $ 180.00 | 1 | $ 180.00 | | |
| M1386-01-295-9261 | SEAT, HELIC | $ 24.00 | 1 | $ 24.00 | | |
| M5340-01-297-0985 | CAP, SECONDARY DISP | $ 22.50 | 1 | $ 22.50 | | |
| M5920-01-304-6745 | FUSEHOLDER | $ 6.20 | 1 | $ 6.20 | | |
| M5305-01-298-5805 | SCREW, MACH,FH.820 | $ 4.20 | 1 | $ 4.20 | | |
| M5310-01-298-2807 | NUT, PLAIN, HEX | $ 5.80 | 1 | $ 5.80 | | |
| M5310-01-297-0890 | NUT, SECONDARY DISPL | $ 61.00 | 1 | $ 61.00 | | |
| M5365-01-300-0091 | RING, RETAIN, THRD UPP | $ 28.50 | 1 | $ 28.50 | | |
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| | | | | | | |
| | | TOTAL COST = | | $ 51,927.40 | | |

# V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

## A. SUMMARY

The objective of this thesis was to provide the inventory manager with a decision support model to assist in determining the most effective mix of repair parts to support a MK 16 deployment. *Effective*, in this case, implies that within the constraints of the scenario defined, this list of parts will provide the least number of stockouts. In inventory problems more parts generally means less stockouts; fully operational spares also means less stockouts. It is common for inventory managers to augment the authorized inventory when repeated shortages tell them that the numbers in the APL don't suffice. However, this scenario is seldom played in reverse; they seldom cut back on an authorized inventory item when experience indicates it is overstocked. The precaution the inventory manager takes is to keep it in inventory "just in case."

Provisioning an inventory strictly from the knowledge and experience of the inventory manager may possibly yield the better list of repair parts. Transferring this expert knowledge and multiplying it throughout the fleet is, however, unrealistic. Conversely, there is little success in applying a prescribed inventory (that was built upon a single, general scenario) to every situation. The proposed spreadsheet model provides support for the inventory manager's decision through the simplified representation of complex mathematical functions and the graphic display of alternatives. The manager still defines the scenario and makes the final decision; a decision no longer based on intuition, but based on a logical examination of the goals and constraints.

In Chapter IV we examined the differences between the repair parts listed in the MK 16 APL and the repair parts

calculated by the spreadsheet model. A few generalizations standout:

1. In all cases, the APL (4) model and the spreadsheet model were closest in output when using the APL's assumptions of scenario (OPTEMPO = 1, lead time = 90 days).

2. Even when the models were close, the APL provided substantially greater protection for low demand items, mostly considered insurance items, than it did for high demand items. The spreadsheet maintained the low demand and high demand items with equally high protection. By reducing several insurance items from 0.999 to 0.995 for example, many demand items' protection could be raised from 0.900 to 0.995.

3. As the scenarios moved further from the APL's scenario assumptions, the APL maintained good protection for items with low demand but failed to provide support for high demand items. There was no significant difference between these protection levels with the spreadsheet model.

4. In all cases, the spreadsheet model was able to provide higher average protection, higher minimum protection and lower costs.

An important assumption in the repair parts selected for this study was that they are all mission essential. The spreadsheet model looks past the insurance/demand issue and focuses on the probability of demand. Where a single part may have an APL authorization of one providing a protection level of 0.995, having no parts may still provide a protection of 0.980. If this were a high cost item, the funds could be applied to several low cost/high demand items where an additional part may boost protection from 0.910 to 0.980. The spreadsheet model automatically balances these costs to achieve the highest average protection available.

## B. CONCLUSIONS

### 1. OPTEMPO and Lead Time Estimates Require Greater Flexibility

Invaluable for fleet-wide provisioning, the assumption of a 90-day lead time and a forecasted demand based on the past ten months' average demand does not accurately model the case for an EOD Det. The 90-day lead time is being modified for much of the fleet, but will likely result in an inflexible model that is accurate for many, but not all, situations. The inventory manager supporting both non-deploying EOD Dets within the continental U. S. and EOD Dets in the Indian Ocean, Korea, and Japan needs the flexibility to set the lead time estimate to achieve the most appropriate protection within the constraints of budget.

OPTEMPO of an EOD Det in training, during exercises, and on a peacetime deployment varies dramatically from that experienced during Desert Storm. Our spreadsheet model allows the command flexibility in supporting a forecast of OPTEMPO; this puts control of the command's resources back into the hands of the Commanding Officer.

### 2. Decrease O-Level Insurance Items: Increase O-Level Demand Items

Insurance items provide a guard against an unexpected failure. Their history of demand indicates that they are unlikely to fail. (Less than 2.5 per 100 per year for some). Their protection level averages much higher than for a demand item. This distinction is important early in the life-cycle of an equipment as SPCC accumulates demand data. Equal treatment permits a substantial increase in overall protection level with no increase in cost.

A second purpose of insurance items is to protect against an increase in failures as the equipment ages. This justifies procurement and stocking of insurance items by SPCC, or at

major stock points like the parent commands. The large number of insurance items maintained at the O-Level implies that the failures will happen suddenly and unexpectedly, fleet-wide, before SPCC can respond as a consequence of increased BRF values. Stocking these items in smaller quantities at the parent commands provides easy access to the EOD Dets. The additional protection provided to insurance items detracts from the protection levels of the demand items. The result is compensation by the inventory managers with augmented inventories and spare MK 16 in lay-up deployed to ensure protection.

### 3. Allocate Repair Parts by Increments, Not Groupings

The groupings in APL columns (5-8) and (9-20) force commands into different levels of readiness. If one facet of readiness is whether or not the command can affect timely repairs, those commands with twenty MK 16 are less ready than the commands with nine. If an average protection level of 0.993 is deemed adequate for a command with nine MK 16 at a cost of $51,055, is 0.956 inadequate at the same cost for a command with twenty MK 16? More significantly, the command with twenty MK 16 operates with a minimum protection level of 0.758 while the command with nine enjoys a minimum of 0.970.

Another problematic case is the inherent protection levels associated with being on the cusp of a grouping. To describe this situation we will use the Desert Storm scenario detailed in Chapter IV, with a lead time of 45 days, OPTEMPO = 5. When evaluating this scenario for an EOD Det operating with five MK 16 provisioned from the APL (5-8) column, and an EOD Det operating with four MK 16 and provisioned from the APL (4) column we receive significantly different protection levels. The EOD Det with five MK 16 would experience an average protection level of 0.9630 and a minimum of 0.7460. This compares to the EOD Det with four MK 16 average of 0.9503

and minimum of 0.4906. Despite accomplishing 25% more diving hours with the additional MK 16, the EOD Det with five MK 16 would experience an average of 25% *less* stockouts.

The proposed spreadsheet approach eliminates the need for grouping the quantities of systems and permits exact calculations. The danger is that, during this evaluation by inventory managers, the EOD Det with five MK 16's protection will be brought down to match that of the EOD Det with four MK 16 in the interest of cost savings. This would likely lead to greater hoarding of parts and additional spare MK 16 deployed to protect against stockouts. The goal of the calculation should be to determine the greatest protection level possible and take the cost savings from the reduced hoarding, reduced capital tied up in spares, and reduced CASREPS.

## C. RECOMMENDATIONS FOR FURTHER RESEARCH

Four areas within this thesis suggest additional research. First, introduce simulation modeling to the scenarios discussed in Chapter IV. Simulation modeling would expand our understanding of the probabilistic relationships as events change over time. By avoiding more of the constraining assumptions of the spreadsheet, simulation allows us to study the dynamic behavior of the supply pipeline.

Second, this thesis focuses on supporting the end-user through allowing greater flexibility in provisioning their repair parts inventory. We have not discussed how this flexibility might affect the repair parts pipeline upstream. The influence of this changing pool of repair parts at the O-Level on SPCC requires additional attention.

Third, this thesis relies heavily on the strength of our OPTEMPO and lead time estimate, and on BRF. Accurate estimates require sustained data collection efforts, evaluation and updating. Designing and implementing this feedback system and extrapolating the information to real world worst

case scenarios would strengthen the inputs required for the spreadsheet model.

Fourth, the true value of a spare MK 16 to an EOD Det is unclear. What is the value in terms of increased readiness and what is the true cost of the spare MK 16? If there is only a small penalty for deploying additional spare MK 16, there may be important savings realized by reducing or eliminating the repair parts inventory. Additionally, with reliable and short lead times, the parent command might function as a intermediate maintenance facility. These concepts for reducing the O-Level maintenance and inventory burden on the deployed EOD Det are areas worth investigating.

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